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TOXICITY TESTING OF SOIL SAMPLES FROM JOLIET ARMY AMMUNITION PLANT, IL

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13. ABSTRACT *(Maximum 200 words)*
Environmental toxicity testing and soil chemical analyses were performed as part of an ecological risk assessment of the Joliet Army Ammunition Plant (JAAP), Joliet, IL. Test soils were collected from six sites at the plant (a load and pack area, two open burning areas, a lead azide area, a 2,4,6-trinitrotoluene (TNT) manufacturing site, and an evaporation bed). Control soil samples were collected from an adjacent area. Soil toxicity was determined using early seedling growth and vigor tests, earthworm survival and growth tests, and the Microtox assays. Relative toxicity of soils was determined within each area based on statistical significance ($p = 0.05$) of plant and earthworm growth and survival, and Microtox EC_{50}. Samples were designated as having high, moderate, or no toxicity. Soil samples that had significant toxicity according to at least one test and representative samples showing no toxicity were analyzed for munitions by High Performance Liquid Chromatography. Chemical residues found in soils included TNT, 1,3,5-trinitrobenzene (TNB), 2,4-dinitrotoluene (2,4-DNT), 2,6-DNT, 2-amino-4,6-DNT, 4-amino-2,6-DNT, cyclotrimethylenetrinitramine (RDX), and cyclotetramethylenetetranitramine (HMX). All soils with no significant toxicity were void of these chemicals.

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PREFACE

The work described in this report was authorized under Sales Order No. 2NIK. This work was started in May 1992 and completed in January 1993.

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QUALITY ASSURANCE

This study, performed under Protocol 23092000X046, was examined for compliance with Good Laboratory Practices as published by the U. S. Environmental Protection Agency in 40 CFR Part 792 (effective 17 Aug 89). The dates of all inspections and the dates the results of those inspections were reported to the Study Director and management were as follows:

Phase inspected	Date	Date reported
Count and thin plants	9 June 1992	11 June 1992
Weigh worms, test end	17 June 1992	23 June 1992
Weigh soil and worms, test start	18 June 1992	23 June 1992
Plant cucumbers, radishes	30 June 1992	7 Aug 1992
Weigh soil and worms, test start	18 Sept 1992	18 Sept 1992
Data and Final report	10 Feb 1993	12 Feb 1993

To the best of my knowledge, the methods described were the methods followed during the study. The report was determined to be an accurate reflection of the raw data obtained.

Dennis W Johnson

DENNIS W. JOHNSON 12 Feb 93
Quality Assurance Coordinator
Research and Technology Directorate

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TOXICITY TESTING OF SOIL SAMPLES
FROM JOLIET ARMY AMMUNITION PLANT, IL

1. INTRODUCTION

The role of the U.S. Army Edgewood Research, Development and Engineering Center's (ERDEC)* Environmental Toxicology Branch in this ecological assessment was to determine baseline environmental toxicity data on the soils from various sites located at the plant. This study was part of a joint effort between the U.S. Army's Environmental Hygiene Agency (AEHA) and ERDEC personnel. Members of ERDEC went to Joliet Army Ammunition Plant (JAAP) to develop a sampling plan, identify potentially contaminated areas, determine sampling sites, and obtain soil samples. Center personnel were responsible for the terrestrial toxicity data for this site. This section reports ERDEC program results. The data generated from these studies will be used to develop an ecological risk assessment for JAAP.

Determining the environmental toxicity of explosives and metals is important in developing an ecological risk assessment for this site. Standardized toxicity tests have been used successfully in risk assessments at other terrestrial sites.[1,2] To adequately assess the toxicity of chemicals to the terrestrial community, it is important to determine effects at several trophic levels. Plants (seed germination and early seedling growth test), earthworms (survival and growth rates), and Microtox fluorescent bacteria tests (reduction in light output), representing three trophic levels, were chosen for this study.

The use of plants and earthworms as measurement endpoints was done for several reasons. One reason is that chemicals may adversely damage the ecosystem and negatively impact wildlife that feed on plants (e.g., deer) and earthworms (e.g., the upland plover, an avian species of concern in Illinois). In addition, earthworms are considered key organisms in the soil community. They increase the fertility of soil by increasing the availability of nutrients, and they are also an important link in the food chain. Earthworms are important to the terrestrial ecosystem and therefore, their use in assessing the hazards of chemicals to the ecosystem is important.

The Microtox Assay (MTX Assay) has been for assessing toxicity of contaminants in sediments from extractions/leachates. In a review paper, Munkittrick et al.[3] compared the relative sensitivities of Microtox and three aquatic acute lethality tests. The results varied with extraction technique as did bacterial sensitivity based on chemical characteristics of contaminants. However, the MTX Assay was determined to be good for assessing relative differences between samples. Furthermore, as a result of investigations of the toxicity of sediment porewater and extracts, the assay is regarded as a valuable tool for toxicity screening of sediments when used in a battery of tests that contain organisms of varying sensitivities.[4] The standardized test is considered rapid, simple, and inexpensive, and therefore, advantageous for the comparative evaluation of a large number of samples in a timely manner.

2. MATERIALS AND METHODS

2.1 Soil Sampling Sites.

Soil samples were collected from six sites. The sites and number of samples collected from each were as follows:

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*Formerly known as the U.S. Army Chemical Research, Development and Engineering Center.

- Burning ground on the manufacturing side of the plant, designated as Area 2 (15 samples)
- Load-and-pack burning ground, designated as Area L2 (33 samples)
- Group 1 load-and-pack area (31 samples)
- TNT ditch complex (32 samples)
- Lead Azide area (13 samples)
- Group 61 (7 samples)

These sites were selected based on a preliminary survey which indicated potential for contamination with munitions, munition residues, and/or metals.

2.2 Collection of Soil Samples.

Soil samples were collected from specific sites using a beryllium spade. Each site was cleared of vegetation and debris down to the soil level. The spade was used to remove the soil from a circular pattern approximately 8-10 in. in diameter and 6 in. deep. The soil was then placed into a double plastic bag and secured with twine. The bag was labelled with the site location and date of collection. All collected samples were transported to ERDEC by AEHA personnel.

2.3 Preparation of Soil Samples.

Soil samples were sieved through a 5 mm^2 mesh wire screen to remove large rocks, twigs, leaves, and other debris. After sieving, the soils were placed back into their original plastic bags to retain soil moisture. Dry-fraction determinations and water-holding capacity for each sample was done to determine the quantity of water required to bring the soil up to field moisture levels before phytotoxicity and earthworm toxicity testing could be conducted.

2.4 Dry Fraction Determinations.

The dry fraction of each soil sample was determined by placing 2-3 g of soil into a weighed aluminum weighing pan. After a total weight was obtained, the pans were placed into a drying oven (110 °C) for 3 days. At the end of this time, the pans were weighed again to obtain a dry weight. The dry weight divided by the initial weight yielded the dry fraction.

2.5 Water-holding Capacity Determination.

Subsamples from each representative soil type were used to determine the water-holding capacity. This was accomplished by placing a known amount of soil (approximately 10 g) into a 25- by 45-mm polyethylene column sealed to a ceramic plate. The ceramic plate was placed into a high-density polyethylene end-cap and sealed around the edges with silicone sealant. A vacuum line was attached to the bottom of the end-cap, below the ceramic plate. The end-cap was placed in an environmental chamber. The soil in the columns were wetted with distilled water and allowed to settle for 4 hr. Additional water (10 mL) was then added to each column (eight columns/end-cap). The vacuum pump was turned on (vacuum set at 0.3 atmospheres) and the columns remained under vacuum for 24 hr. At the end of this time period, the soil from each column was removed and reweighed. The difference between the initial weight and final weight of the soil was used to determine water-holding capacity using the following formula:

$$\text{WHC} = \frac{(100\%) \times (\text{final wt}) - (\text{dry fraction}) \times (\text{initial wt})}{(\text{dry fraction}) \times (\text{initial wt})}$$

2.6 Toxicity Testing.

2.6.1 Phytotoxicity Testing.

The screening regimen for determining phytotoxicity was adapted from the U.S. Environmental Protection Agency's (USEPA) Early Seedling Growth Toxicity Test[5] (Toxicology Division SOP #'s LTP-62 - 65 and Research Protocol # 23092000X046). The screening regimen used for all of the plant tests is summarized below.

For each soil tested, approximately 1000 g of pea gravel was placed into a 150 mm (diameter) flower pot. A single layer of cheesecloth was placed on top of the gravel and 800 g (dry weight) of soil was added to the pot to bring the soil level to within 1 cm of the top. Two pots of each soil sample were made-up in this manner to test two species of plants (i.e., cucumber and radish).

Cucumber and radish seeds were sorted to remove broken or malformed seeds and to obtain seeds of similar size. There were 20 cucumber seeds planted in one pot and 20 radish seeds were planted in the other pot. After germination, the seedlings were thinned to the 10 most uniform per pot. "Day 1" of treatment was determined when 50% of the total number of seeds had germinated. A record of the rate of seed emergence was made over the 14-day study period. Plant height measurements were taken four times during the study period. Any plant abnormalities (e.g., chlorosis, necrosis, etc.) were noted. A final measurement was made on the day plants were harvested (Day 14).

Data were produced on plant heights, survival rate, and seed emergence rates. Statistical evaluations of plant data included Analysis of Variance (ANOVA) and Newman-Keuls pairwise comparison of means.[6]

2.6.2 Earthworm Toxicity Testing.

Earthworm toxicity testing utilizes the earthworm *Eisenia foetida*. The survival rates and the differences between the initial weights and the final weights of the earthworms are used as indices of toxicity.

The test methods used for earthworm toxicity studies were adapted from Karnak and Hamelink[7] and Neuhauser et al.[8] The screening regimen for determining earthworm toxicity (Toxicology Division SOP # LTP-48 and Research Protocol # 23092000X046) is summarized below.

Earthworms (*Eisenia foetida*), originally purchased from Bert's Bait Farm (Irvine, KY), were bred and housed in styrofoam coolers in our laboratory. Earthworms were housed under controlled temperature in a low-temperature incubator (21.0 $\pm$ 0.2 °C) during the course of the studies.

An earthworm toxicity test consisted of placing five earthworms into each of two 600-mL glass beakers per soil sample (i.e., two replicates per sampling location). For each beaker, 200 g of soil (dry weight) from a sampling location was mixed in a food blender to which a sufficient quantity of distilled water was added to bring the soil moisture level up to field capacity. This was mixed for approximately 3 min until uniformly mixed and then placed into one of the beakers. The procedure was repeated for the other beaker.

After the beakers were prepared, 75-100 earthworms were removed from one of the styrofoam coolers and put into a plastic dishpan. The earthworms were quickly rinsed in tap water and excess water drained from the pan. Five earthworms were arbitrarily picked, quickly blotted with a paper towel, and weighed as a group. They were then placed in one of the beakers. After five earthworms had been added to each beaker, the beakers were covered with nylon screen and cheesecloth held in place by a rubber band. The beakers were placed in plastic trays within the incubator. Water was added to the trays to help prevent the soil in the beakers from drying out. The incubator lights were set for continuous operation. Because earthworms are photophobic, the light encouraged them to burrow into the soil and helped prevent them from crawling out of the beakers.

The earthworms were retained in the incubator for the 2-week exposure period. Beakers were rearranged in the trays at the end of the first week. On Day 14, the earthworms were removed from each beaker and reweighed to obtain a final weight. The earthworms were also examined for their physical condition. Any changes in physical condition (e.g., color, texture, motility, etc.) were noted.

The statistical methods used to evaluate the earthworm data were the Analysis of Covariance (ANCOVA) to test the weight differences and the Newman-Keuls pairwise comparison of means.[6]

2.6.3 Microtox Analysis.

Photobacterium phosphoreum, a luminescent marine bacterium, was the test organism used in the aquatic assay. Exposure of the organisms to toxicants typically lowers light output in proportion to toxicity. The resulting data was tabulated and reduced to present the effective concentration at which light output was reduced by 50% (EC_{50}). Standardization of the test was maintained by supplying test cells in a freeze-dried form designed to capture and maintain the optimum physiological state. The method provided consistent sensitivity and specificity of the test.

Data Analysis.

The Microtox Data Collection and Reduction System calculated the EC_{50} from data entered into a computer from the 5- and 15-min interval readings. Data reduction was based on a log-log transformation of concentration and effect using a least-squares regression line. The effect (light lost) was expressed as "gamma" and defined as the ratio of the light lost to the light remaining. The median, or 50% effect, was represented by a gamma of one. Residual variance (the measure of the variation of the log gamma about the regression line) was used to compute a 95% confidence factor. This factor, described by the upper and lower concentration, defined the EC_{50} with 95% accuracy. All assays were conducted in accordance with interagency protocols and standard laboratory procedures.[9]

2.6.4 Leachate Extraction.

Subsamples were taken from soils originally collected along designated transects at JAAP. A 150-g sample was placed in a tared 1-L precleaned EP Tox Jar (Scientific Specialty Services, Inc., Randallstown, MD). The CO_2 saturated ASTM type 1 water (600 mL) was added to each jar. The jars were agitated end-over-end in a rotary extractor (Lars Lande, Whitmore Lake, MI) at 30 rpm and 20 $\pm$ 2 °C for 48 hr. The mixture was allowed to settle for 2 hr, then filtered through 0.45-μm membrane. Extracts were collected and expressed as volume of extract:mass of original soil sample.

Following measurement of pH, assays were performed within 72 hr of mixing. The pH of the samples was adjusted to six to eight with either 0.5 M NaOH or 10% HCL. This preserved the optimum pH range for the organisms' sensitivity and viability.

Extracts (approximately 3 mL) were centrifuged (11,000 rpm for 17 min at 4 °C) to provide samples free of turbidity. The supernatant was stored at 5 °C until used in the assay.

All EC_{50}s are percent of the soil leachate and are from 15-min exposures unless otherwise noted. Choice of the 100% Microtox Assay test version was based on the requirement of an EC_{50} endpoint and the ability to test close to 100% of the leachate should some samples be low in toxicity (basic assay tests up to a maximum of only 45% sample).

The 100% assay was conducted within the temperature controlled (15 °C) wells of a photometer (Microtox Analyzer) and consisted of four sample dilutions (ranging from 11.3 to 91% of extract diluted by a factor of two) and 1 blank. Reagent (*Photobacterium phosphoreum*) was added directly to sample dilutions. All solutions were prepared to yield final concentrations of 2% NaCl, the natural environment of the microorganism. Readings were taken at 5- and 15-min intervals to measure any decrease in light output. The blank served to correct readings for time-dependent drift in light production. Light lost to light remaining was calculated, and further data reduction produced an EC_{50}.

2.6.5 Analytical Methods for Determining Concentrations of Explosives.

Analytical determinations of explosives in soil by High Performance Liquid Chromatography (HPLC) entailed grinding air-dried soil samples and extracting into acetonitrile with 18 hr of sonication at 20 °C.[10] Extracts were then centrifuged at 3900 X G for 15 min and analyzed by HPLC. An internal standard for nitroaromatics, 1,3-dinitrobenzene (DNB), was incorporated. Because the efficiency of extraction of the nitroaromatic explosive compounds was similar to that of DNB, a simplified recovery correction system was possible. All soil samples were extracted with acetonitrile containing 2.5 mg L^{-1} (ppm) of DNB as an internal standard. Observed concentrations of nitroaromatics in the extraction mixture were corrected for losses of internal standard that occurred during the extraction process, and also for any increases in concentration due to evaporation of the extraction solvent. Generally, adjustments of recoveries due to gain or loss of the DNB internal standard were insignificant.

Following screening by a gradient HPLC method to determine constituents present, a simpler isocratic method was used to substantiate identification and to quantitate contaminants.

JAAP soil samples were analyzed for cyclotrimethylenetrinitramine (RDX), cyclotetramethylenetetranitramine (HMX), trinitrotoluene (TNT), 2,4-dinitrotoluene [2,4-DNT], 2,6-dinitrotoluene [2,6-DNT], trinitrobenzene [TNB], 2-amino-dinitrotoluene [2-amino-DNT], and 4-amino-dinitrotoluene [4-amino-DNT].

The quality control program for this study assessed sample preparation, analyte recovery, and analytical precision and accuracy, and included as its basis the Quality Assurance Program of the U.S. Army Toxic and Hazardous Materials Agency.[11] The respective criteria of detection were calculated using the computerized program that defines the criterion of detection as the lowest certifiable limit for quantitation.

3. RESULTS

Data from phytotoxicity, earthworm, and Microtox tests were summarized by site. Each test was reviewed individually, emphasizing soil sampling locations where toxicity was statistically significant ($p < 0.05$). To assess the overall toxicity of each soil sample and to prioritize soil samples for further analyses, soils were classified as being either highly (H) toxic (survival rates were <30% and growth reduction was significant at $p < 0.05$ for earthworm and phytotoxicity tests; EC_{50} was <30% for the Microtox test), moderately (M) toxic (survival rates were 30-70% or growth reduction was significant at $p < 0.05$ for earthworm and phytotoxicity tests; EC_{50} was 30-70% for the Microtox test), or not significantly (NS) toxic (survival rates were >70% and growth reduction was not significant at $p < 0.05$ for earthworm and phytotoxicity tests; EC_{50} was >70% for the Microtox test).

The 15-min EC_{50} Microtox test was used for comparisons (depending on toxic response over time and quality of data as determined by confidence factors). The 5-min EC_{50} was substituted if confidence factors were too large. However, a comparison of the EC_{50} values for the 5- and 15-min readings were not found to vary enough to place the sample into a different toxicity category.

Data and statistical information for all of the bioassays are given in the appendixes.

3.1 Area 2 Soils.

Area 2 was a burning ground for waste explosives. Sampling sites are presented in Figure 1. The results of phytotoxicity, earthworm toxicity, and Microtox tests were compared to determine a relative degree of toxicity for these soils. These results are given in Table 1.

Sampling location Q2 and Q4 were highly toxic for all tests. Sampling location Q1, located midway between Q2 and Q4 on an east-west transect, was highly toxic according to the Microtox test but not significantly toxic according to the other tests (Table 1). The only other locations showing toxicity were R3 (Microtox - M) and S6 (earthworm - M), both of which were far removed from the Q transect. All other locations were not significantly ($p < 0.05$) toxic for all assays.

Table 1. Toxicity of Area 2 Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
R3	NS	NS	NS	M
S6	M	NS	NS	NS
Q1	NS	NS	NS	H
Q2	H	H	H	H
Q4	H	H	H	H
No significant toxicity for all tests: R2, R4, R5, R6, S2, S3, S4, S5, Q3, Q5, and Control				

Toxicity level: H = High; M = Moderate; NS = No Significance

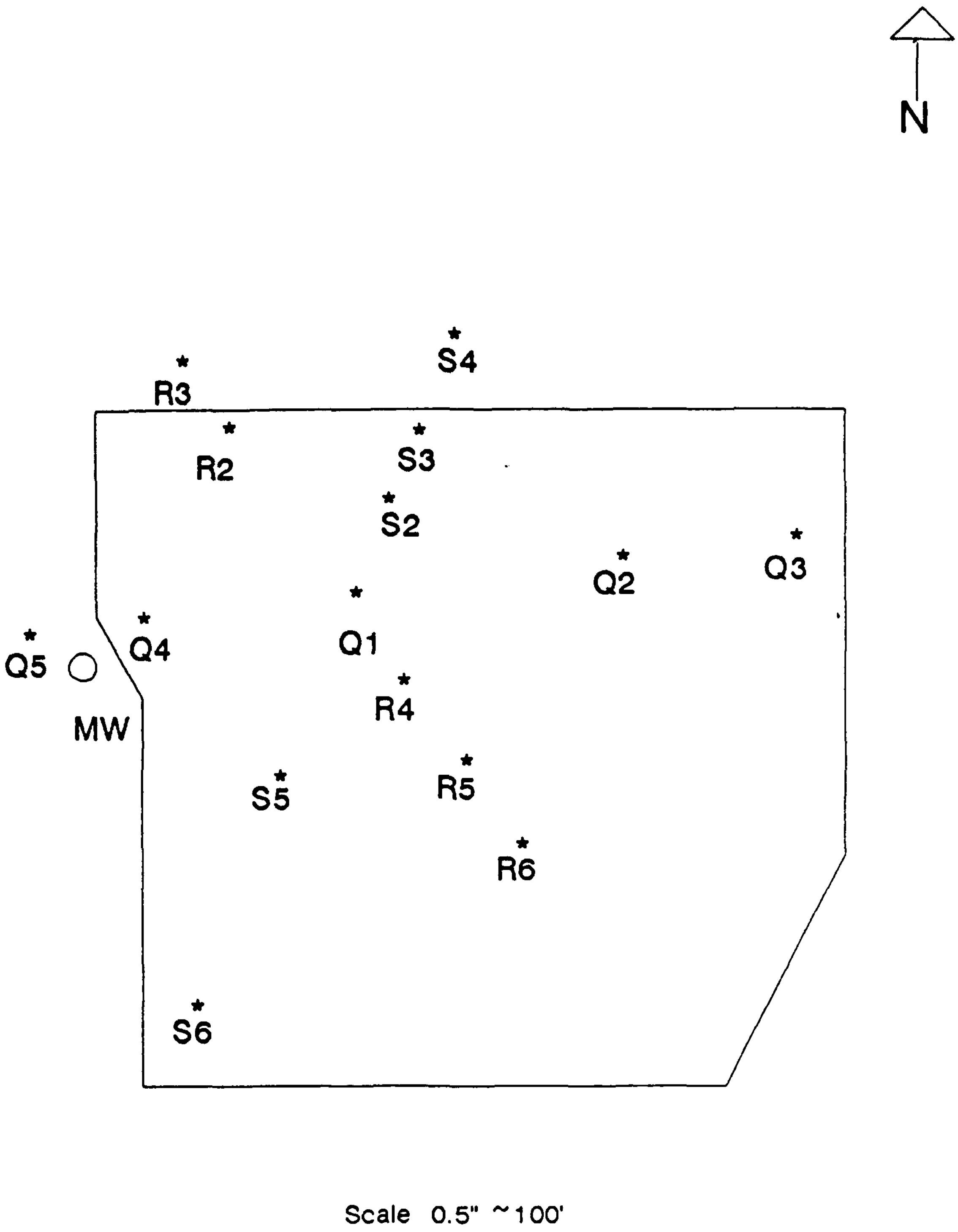


Figure 1. JAAP - Area 2 Manufacturing Side Explosive Burning Ground

The ANOVA of the mean plant heights of cucumbers grown in Area 2 soils indicated a significant ($p < 0.0001$) difference between sites. The survival rate was 100% for all soil samples except Q4 (60%) and Q2 (50%), which also had the lowest mean plant heights. There was a 95-100% seed emergence rate for cucumbers in all soils except for the Q2 and Q4 soils, which only had a 40% emergence rate for each. Similar results were found for radishes. The ANOVA of mean plant heights indicated a significant ($p < 0.05$) difference. Survival rate was 100% for all soils except for Q2 (80%) and Q4 (60%). The seed emergence rates were 85-100% in most soils. However, the emergence rate was only 50% in Q2 soil and 65% in Q4 soil, which was similar to the cucumber results. The Newman-Keuls pairwise comparison of means indicated a significant ($p < 0.05$) difference between the cucumbers and radishes grown in Q2 and Q4 soils, which had smaller average heights, and the other soils.

The results of the earthworm toxicity test indicated lethal and sublethal effects at certain sites. The ANCOVA of earthworm weights showed that the difference between the initial weights and final weights was significant ($p < 0.0006$) among the various sites. The survival rate was 80-100% for all soil samples except Q2 and Q4 (0%) and S6 (70%).

Results of the Microtox assay were considered highly toxic for sample locations Q1, Q2, and Q4 because their EC_{50} values were 29.2, 5.7, and 5.8%, respectively, when compared to other soils at this site. The R3 had an EC_{50} of 67.5% and S5 had an EC50 of 85.9% (derived from a 5-min assay because data from the 15-min assay were insufficient). All other soils at this site showed no toxicity ($EC_{50} > 100\%$).

3.2 Area L2 Soils.

Area L2 was an explosive burning ground on the load-and-pack side of the plant. Sampling locations are shown in Figure 2. Toxicity was greatest in the central portion of this area, soil sampling locations K1-3, L1-3, M1-3, N1, N1-2, and P1, as indicated by the results of the four toxicity tests (Table 2). Toxicity generally decreased with increasing distance from this centralized area. Samples closest to this area (L5, M6, N5, N6, and O1) had variable toxicity among tests, whereas soils around the perimeter of the toxic area were not significantly ($p < 0.05$) toxic except for P1, which was highly toxic for all tests.

The ANOVA of the mean plant heights of cucumbers grown in Area L2 soils indicated a significant ($p < 0.0001$) difference between locations. The survival rate was 100% for all soils except for the following locations: P1 (20%), N2 and L3 (10%), and K1, K2, K3, L1, L2, M1, M2, M3, and N1 (0%). Seed emergence rates for cucumbers were 75-100% in all soils except for L3 (5%), L5 (50%), N2 (5%), P1 (10%), and P2 (60%).

The ANOVA of mean plant heights for radishes also indicated a significant ($p < 0.0001$) difference between locations. Survival rate was 100% for all soils except L5 (80%), N1 (10%), and K1, K2, K3, L1, L2, L3, M1, M2, M3, N2, and P1 (0%). Seed emergence rates for radishes were 80-100% in all soils except for K2 (5%), K5 (60%), L1 (20%), L2 (10%), L3 (20%), L5 (40%), N1 (5%), and K1, K3, M1, M2, M3, N2 and P1 (0%).

The Newman-Keuls pairwise comparison of means indicated a significant ($p < 0.05$) difference between cucumber plants grown in N6, L5, L3, N2 and P1 soils and the other soils. The Newman-Keuls test for radishes indicated a significant ($p < 0.05$) difference between the L5 and N1 soils and the other soils tested.

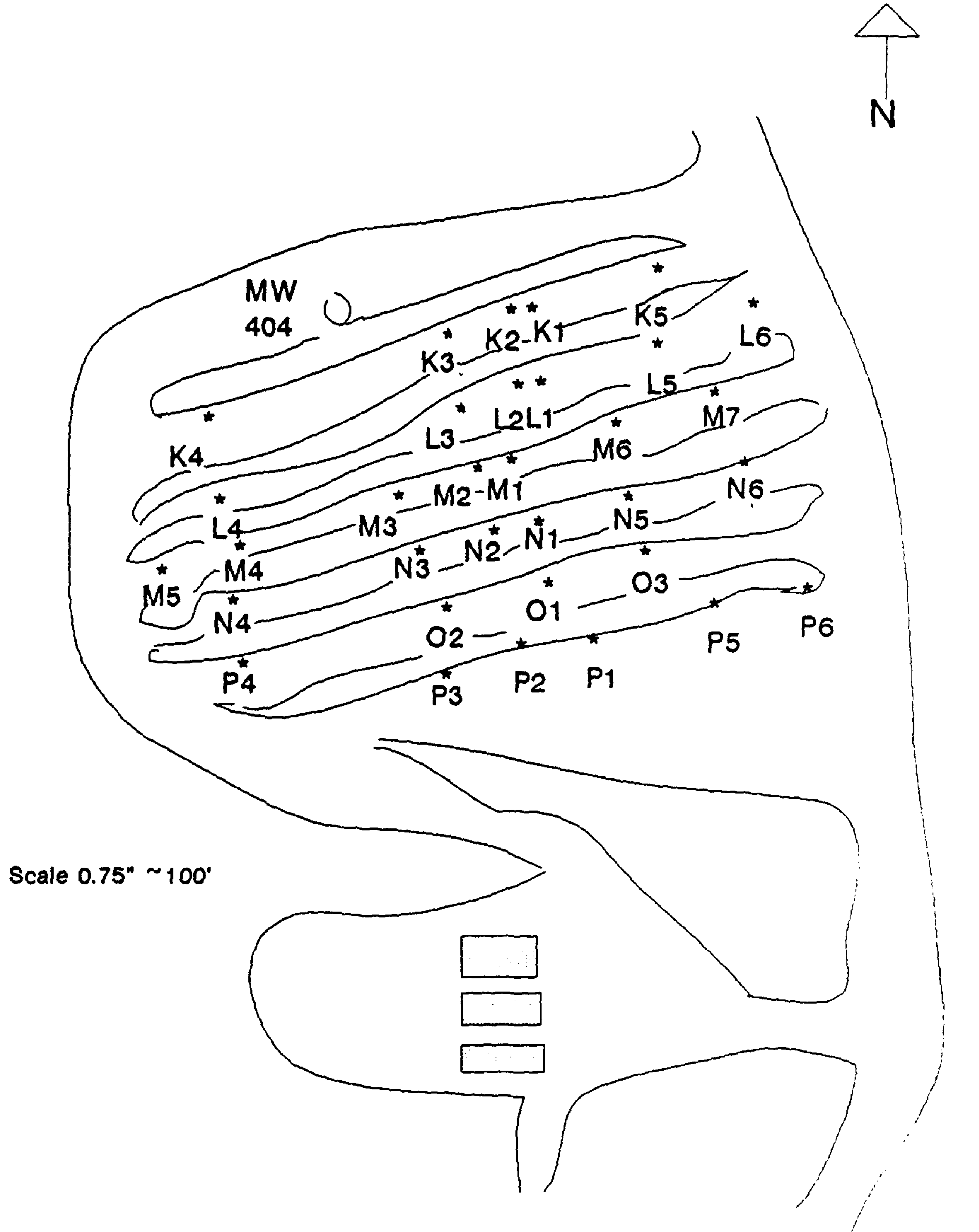


Figure 2. JAAP - Area L2 LAP Side Explosive Burning Ground

Table 2. Toxicity of Area L2 Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
K1	H	H	H	H
K2	H	H	H	H
K3	H	H	H	H
L1	H	H	H	H
L2	H	H	H	H
L3	H	H	H	H
L5	H	H	H	H
M1	H	H	H	H
M2	H	H	H	H
M3	H	H	H	H
M6	NS	NS	NS	M
N1	H	H	H	H
N2	H	H	H	H
N5	NS	NS	NS	H
N6	NS	M	NS	H
O1	H	NS	NS	NS
P1	H	H	H	H

No significant toxicity for all tests: K4, K5, L4, L6, M4, M5, M7, N3, N4, O2, O3, P2, P3, P4, P5, P6, and Control

Toxicity level: H = High; M = Moderate; NS = No Significance

The results of the earthworm toxicity test from this location indicated lethal and sublethal effects at certain sites. The ANCOVA of earthworm weights showed that the difference between the initial weights and final weights was significant ($p < 0.01$) among the various locations (Table 2). The survival rate was 80-100% for 20 of the soil samples but 0% for 12 other locations.

For Microtox, soils K1-3, L1-3, L5, M1-3, N1, 2, 5, and 6 had EC_{50}s below 22% and were considered highly toxic (the EC_{50} for L3 was derived from a 5-min assay because data from the 15-min assay were insufficient). Soil M6 had an EC_{50} of 57.7%. All other soils in this area were non-toxic and had EC_{50}s of 100%.

3.3 Group 1 Soils.

Group 1 was a load-and-pack operation from World War II to 1975 (Figure 3). Moderate to high toxicity was found for one or more of the tests at sampling locations A2-A5, B5, C1, D1, E1, E2, G1, G2, I1, and I2 (Table 3). High toxicity for all tests was found at A2, A2', D1, E1, G1, G2, I1, and I2. Results of toxicity testing at all other locations were not significant. Table 3 compares the results of the four bioassays at this site.

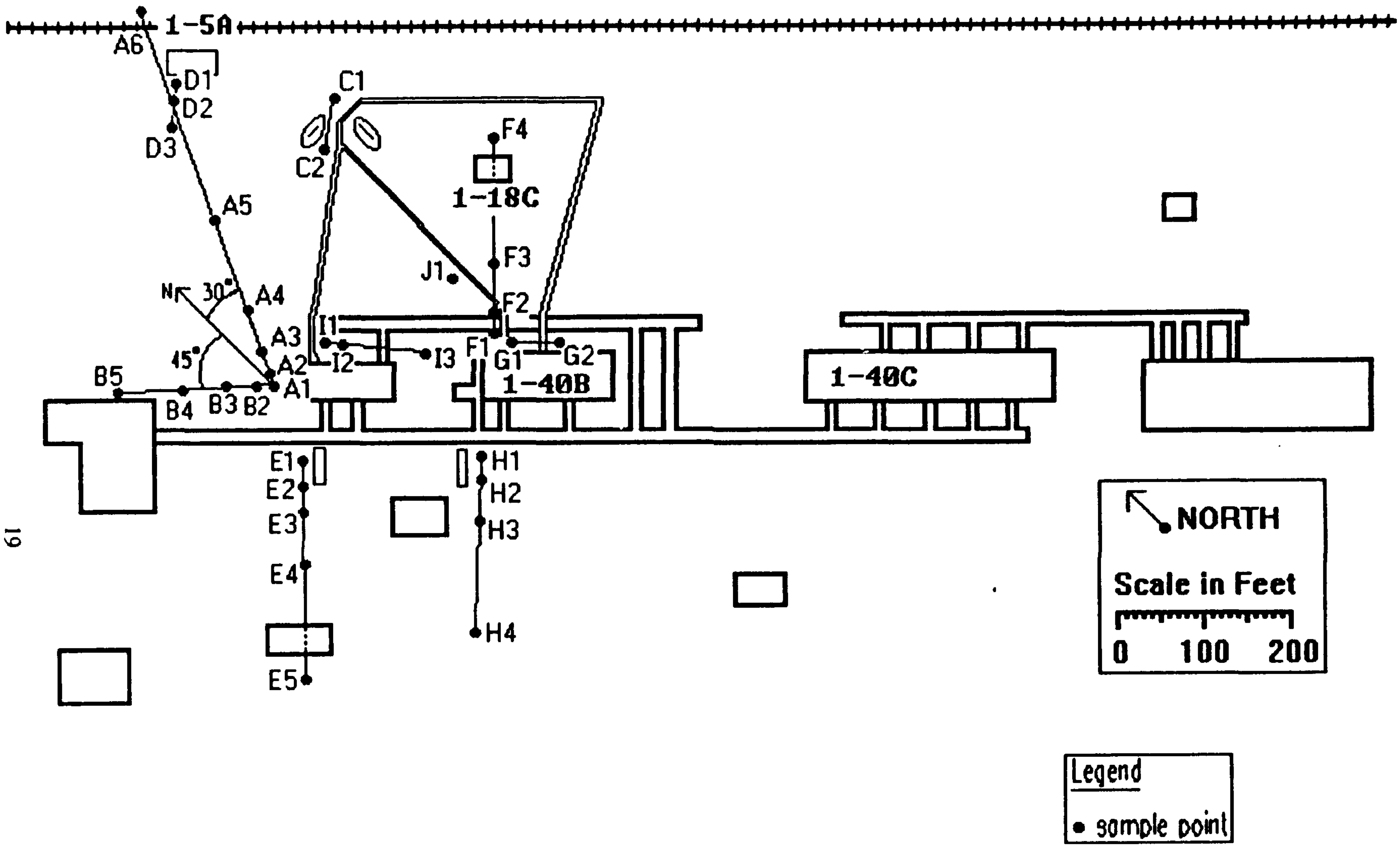


Figure 3. L7 - Sample Sites Group 1

Table 3. Toxicity of Group 1 Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
A2	H	H	H	H
A2'	H	H	H	H
A3	NS	NS	NS	M
A4	NS	NS	NS	H
A5	H	NS	NS	NS
B5	NS	NS	NS	H
C1	M	H	M	H
D1	H	H	H	H
E1	H	H	H	H
E2	NS	H	M	NS
G1	H	H	H	H
G2	H	H	H	H
I1	H	H	H	H
I2	H	H	H	H

No significant toxicity for all tests: A6, B4, C2, D2, D3, E3, E4, E5, F1, F3, F4, H1, H2, H3, H4, I3, J1, and Control

Toxicity level: H = High; M = Moderate; NS = No Significance

The ANOVA of the mean plant heights of cucumbers indicated a significant ($p < 0.0001$) difference between locations. The survival rate was 100% for all soil samples except A2' (80%), D1 (30%), G2 (20%), G1 and I1 (10%), and A2, E1, and I2 (0%). The seed emergence rates for cucumbers were 90-100% in all soils except for A2' (40%), D1 (15%), G2 (10%), G1 (5%), I1 (5%), and A2, E1, and I2 (0%).

The ANOVA of mean plant heights for radishes indicated a significant ($p < 0.0001$) difference between locations. Survival rate was 100% for all soils except D1 (90%), E2 and G2 (70%), E1 and G1 (50%), A2 (30%), and I1 and I2 (0%). Seed emergence rates for radishes were 70-100% in all soils except for G1 and H1 (60%), E1 (50%), I2 (10%), and I1 (5%). The Newman-Keuls test indicated a significant ($p < 0.05$) difference in mean plant heights between cucumber plants grown in A2', C1, D1, E2, G1, G2, and I1 soils and the other soils. Similar results were found for radishes.

Earthworm test results indicated lethal and sublethal effects at certain locations. The ANCOVA of earthworm weights showed that the difference between the initial weights and final weights was significant at $p < 0.0001$. The survival rate was 75-100% for most of the soil samples. There were no survivors from A2', D1, E1, G1, G2, I1, and I2. Samples A2 and A5 only had a 10% survival rate.

The Microtox test for soils A2, A2', A4, B5, C1, D1, E1, G1, G2, I1, and I2 produced EC_{50}s of <30%. All other soils in this area had EC_{50}s of 100%.

3.4 TNT Ditch Soils.

The TNT ditch complex, located on the manufacturing side of the plant, produced TNT and related explosive compounds from 1942-1977. Sampling locations are given in Figure 4. Sampling locations CC1 and FF3 scored in the high range for all toxicity tests (Table 4). Locations BB2 and CC3 had moderate toxicity for the Microtox test, but were not toxic in the other tests.

Table 4. Toxicity of TNT Ditch Complex Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
BB2	NS	NS	NS	M
CC1	H	H	H	H
CC3	NS	NS	NS	M
FF3	H	H	H	H

No significant toxicity for all tests: AA1, AA2, AA3, AA4, AA5, AA6, BB1, BB3, BB4, BB5, CC2, CC4, CC5, CC6, DD1, DD2, DD3, DD4, DD5, EE1, EE2, EE3, EE4, EE5, EE6, FF1, FF2, FF4, and Control

Toxicity level: H = High; M = Moderate; NS = No Significance

The ANOVA of the mean plant heights of cucumbers soils indicated a significant ($p < 0.0001$) difference between locations. The survival rate was 100% for all soil samples except for CC1 and FF3 (0%). The seed emergence rates for cucumbers were 70-100% in all soils except for AA2 (65%) and CC1 (35%).

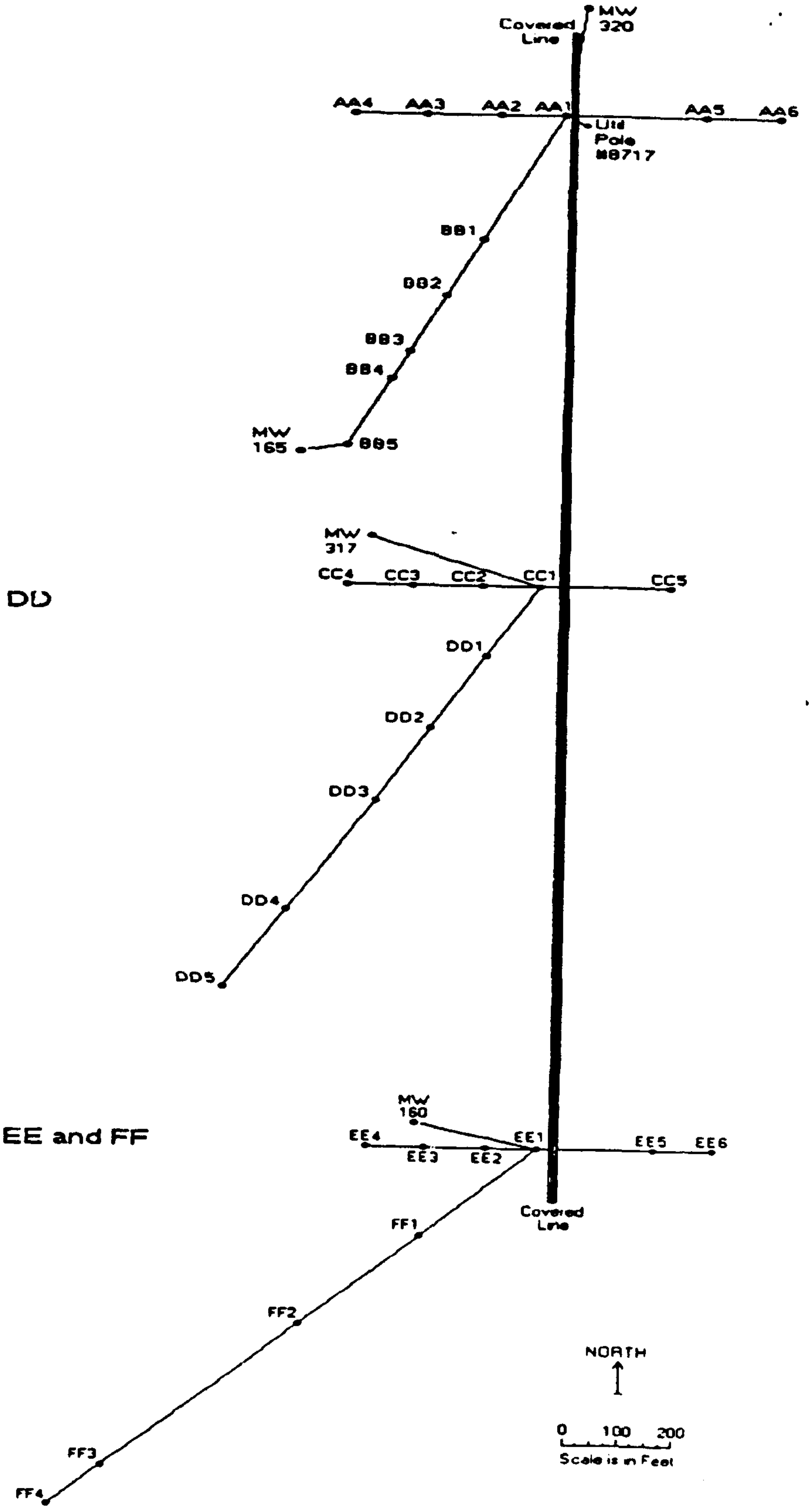
The ANOVA of mean plant heights for radishes also indicated a significant ($p < 0.0001$) difference between locations. Survival rate was 100% for all soils except CC1 (60%) and FF3 (30%). Seed emergence rates for radishes were 90-100% in all soils except for AA6 (60%) and CC1 (20%). The Newman-Keuls pairwise comparison of means indicated a significant ($p < 0.05$) difference in mean plant heights between cucumber plants grown in A2', C1, D1, E2, G1, G2, and I1 soils and the other soils. Similar results were found for radishes.

Earthworm tests produced lethal and sublethal effects at certain locations. The ANCOVA of earthworm weights showed that the difference between initial weights and final weights was significant at $p < 0.0001$. The survival rate was 100% for all of the soil samples except for sites CC1 and FF3 in which there were no survivors.

The Microtox test for soils CC1 and FF3 produced an EC_{50} of 4.8 and 6.1%, respectively. Soil sample BB2 had an EC_{50} of 54.1% and CC3's was 51.2%. All other soils had EC_{50}s of 100%.

3.5 Lead Azide Soils.

This site was used for production of lead azide explosives. Sampling locations are given in Figure 5. A comparison of the tests from this site showed a moderate earthworm toxicity level from II4 (Table 5). This area was suspected to be contaminated with lead; therefore, some of the soil



Sites CC and DD

Sites EE and FF

Figure 4. TNT Ditch Complex

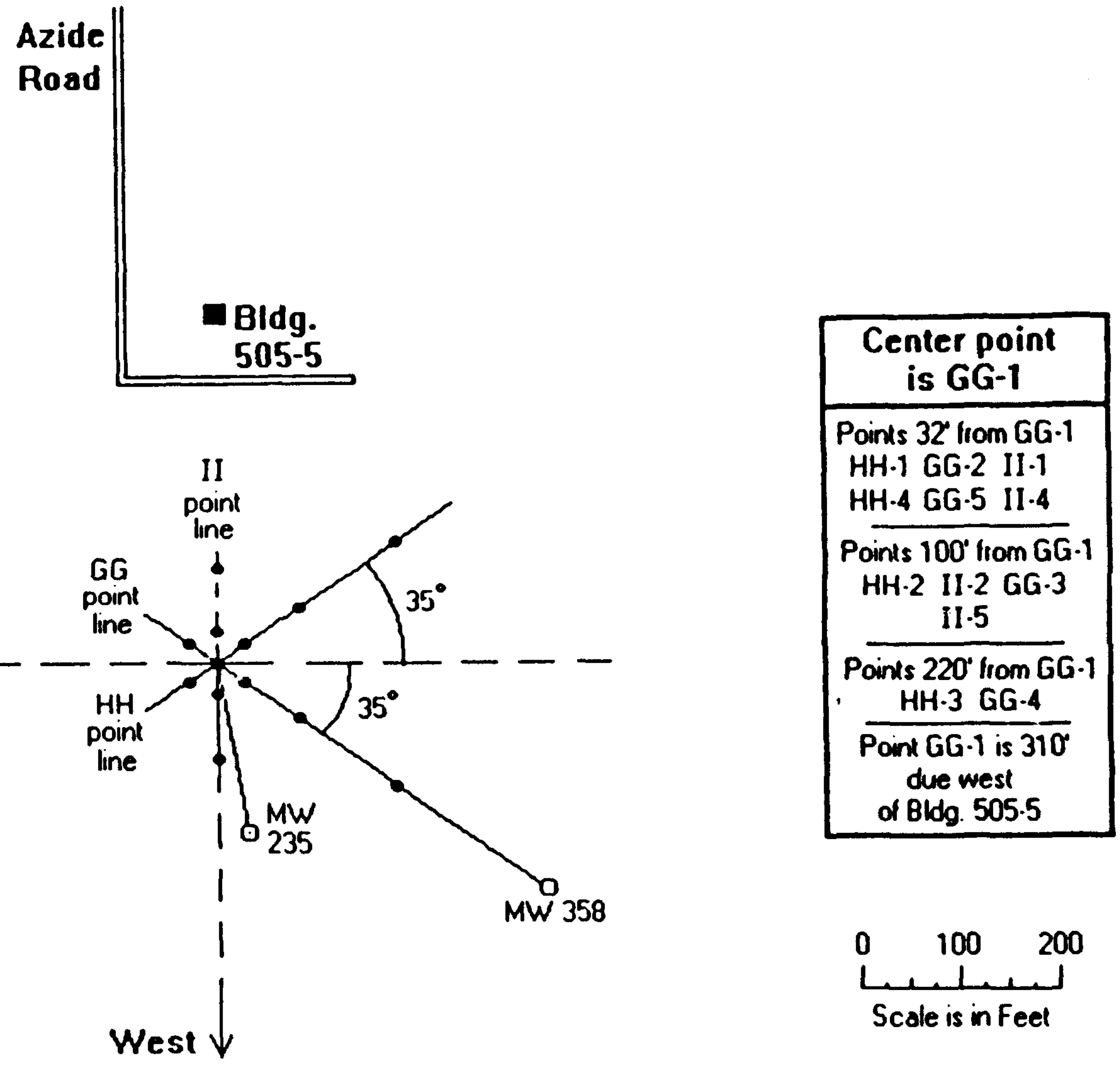


Figure 5. Lead Azide Area

samples were analyzed for lead. Soil from II4 was found to contain an extremely high lead concentration [> 12,000 mg kg^{-1}; (samples analyzed for lead following Toxicology Division's SOP # EMC-12)]. No toxicity was found on earthworms exposed to soils GG1, II1, II5, and II2, which contained 4400, 1800, 1,000, and 16 mg kg^{-1} lead, respectively.

Table 5. Toxicity of Lead Azide Area Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
II4	M	NS	NS	NS
No significant toxicity for all tests: GG1, GG2, GG3, GG4, GG5, HH1, HH2, HH3, HH4, II1, II2, II5, and Control				

Toxicity level: H = High; M = Moderate; NS = No Significance

The ANOVA of the mean plant heights of cucumbers indicated a significant ($p < 0.01$) difference between locations. The survival rate was 100% for all soils tested. The cucumber seed emergence rates were 75-100% for all soils. The ANOVA of mean plant heights for radishes indicated no significant ($p > 0.05$) difference between locations. Survival rate was 100% for all soils. Radish seed emergence rates were 75-100% in all soils. The Newman-Keuls pairwise comparison of means indicated a significant ($p < 0.05$) difference in mean plant heights of II1 and II5 cucumber plants and those grown in GG2 soils. The results on radishes found no significant ($p > 0.05$) difference.

Earthworm test results from this site indicated lethal and sublethal effects at certain locations. The ANCOVA of earthworm weights showed that the difference between the initial weights and final weights was significant ($p < 0.005$). The survival rate was 100% for all of the soil samples except for II4, which had a 90% survival rate.

All soils at this site were relatively nontoxic with a Microtox EC_{50} of 100%.

3.6 Group 61 Soils.

Group 61 was used as a demilitarization area following World War II. A holding pond was used to contain explosive water residue. Soil samples were taken outside the fenced area around the perimeter of this pond. Sampling locations are given in Figure 6. None of the samples were toxic except JJ7, which was moderately toxic to cucumbers (Table 6). The other tests showed no significant ($p < 0.05$) toxicity.

The ANOVA of the mean plant heights of cucumbers indicated a significant ($p < 0.0001$) difference between locations. The survival rate was 100% for all soils tested. The cucumber seed emergence rates were 75-95% for all soils.

The ANOVA of mean plant heights for radishes indicated no significant ($p > 0.05$) difference between locations. Survival rate was 100% for all soils. Radish seed emergence rates were 75-95% in all soils except for JJ2, which had a 65% rate. The Newman-Keuls pairwise

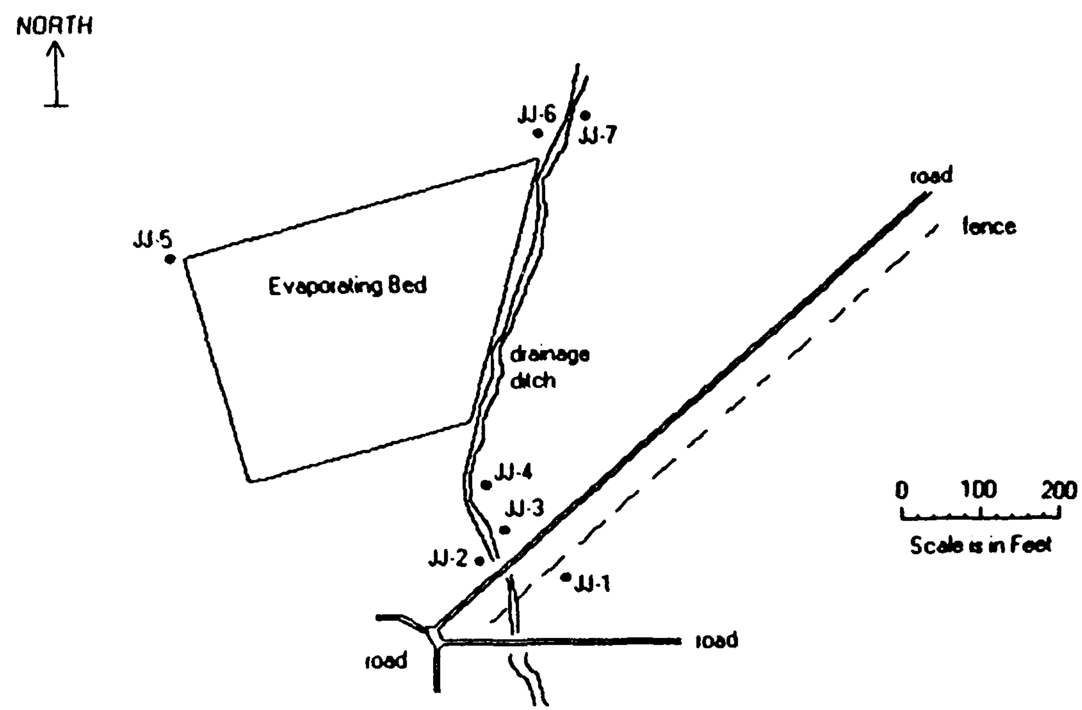


Figure 6. Group 61 - Evaporating Bed Sample Sites

comparison of means indicated a significant ($p < 0.05$) difference in mean plant heights of cucumbers grown in JJ5 and JJ7 soils. The results on radishes found no significant ($p > 0.05$) difference.

Table 6. Toxicity of Group 61 Soils Using Four Bioassay Tests

Sampling Location	Bioassay Test			
	Earthworm	Cucumber	Radish	Microtox
JJ7	NS	M	NS	NS
No significant toxicity for all tests: JJ1, JJ2, JJ3, JJ4, JJ5, JJ6, and Control				

Toxicity level: H = High; M = Moderate; NS = No Significance

Results from the earthworm toxicity test for this site indicated lethal and sublethal effects at certain locations. The ANCOVA of earthworm weights showed that the difference between the initial weights and final weights was not significant at $p < 0.1$. The survival rate was 100% for all of the soil samples except for site JJ1, which had a 90% survival rate.

All soils at this site were relatively nontoxic with EC_{50}'s of 100% for the Microtox test.

3.7 Results of HPLC Analyses.

The types of munitions or munition by-products that were analyzed for from JAAP soils and their respective criteria of detection[10,11] are as follows:

RDX - < 5.8 mg kg^{-1}	2,4-DNT - < 5.7 mg kg^{-1}
HMX - < 2.9 mg kg^{-1}	2,6-DNT - < 5.2 mg kg^{-1}
TNT - < 6.1 mg kg^{-1}	2-Amino-DNT - < 15.0 mg kg^{-1}
TNB - < 2.4 mg kg^{-1}	4-Amino-DNT - < 15.0 mg kg^{-1}

3.7.1 Area 2 Soils.

Area 2 soils had reportable TNT concentrations ranging from <6.1 mg kg^{-1} (the criterion of detection) to 218 mg kg^{-1}. Five Area 2 samples exhibited toxicity for one or more bioassays, but the only locations found to be contaminated with munition(s) or their by-products were Q1, Q2, and Q4. These sites produced at least one "highly" toxic bioassay. Sites R3 and S6 each produced one moderately toxic bioassay, but HPLC analysis indicated no presence of munitions. Table 7 lists the results of the HPLC analysis.

Table 7. Results of HPLC Analysis from Area 2 Soils

Soil Sample	HPLC Analysis (μg/g soil, dry weight)*							
	RDX	HMX	TNT	TNB	2,4-DNT	2,6-DNT	2-Amino-DNT	4-Amino-DNT
R3	0**	0	0	0	0	0	0	0
S6	0	0	0	0	0	0	0	0
Q1	0	0	10	BCD	BCD	0	BCD	BCD
Q2	0	0	91	6	0	0	BCD	BCD
Q3	0	0	0	0	0	0	0	0
Q4	0	0	218	3	7	0	15	17

*Values are a mean of 2 replicates. Values rounded to whole numbers.
**A zero value (0) corresponds to a "none detected" level. "BCD" indicates a concentration of less than the criterion of detection (trace concentration).

3.7.2 Area L2 Soils.

Area L2 soils had reportable TNT concentrations ranging from <6.1 mg kg^{-1} to 19,990 mg kg^{-1}. The TNT contamination was restricted to the central section of the burning ground. Of the 23 L2 soils analyzed, samples from 14 locations were found to contain munitions and munition by-products. The HPLC analysis results are given in Table 8.

Sites with 30 μg/g or greater of TNT had at least one bioassay test exhibiting a "highly" toxic effect. Site M6, with 19 μg/g of TNT, had a "moderately" toxic response in the Microtox test. Site N5 was an exception that had trace amounts of HMX, TNB, 2-Amino- and 4-Amino-DNT, and exhibited a "highly" toxic response in the Microtox test.

3.7.3 Group 1 Soils.

Group 1 had reportable TNT concentrations ranging from less than 6.1 mg kg^{-1} to 87,000 mg kg^{-1}. Twelve of 19 samples analyzed were found to contain TNT (Table 9). Most of the contamination was restricted to an area close to the building proper. However, high levels of TNT were also found at the D1 location.

All of the 12 samples that contained munitions and/or munition by-products (except Site I3) had one or more "highly" toxic responses in the bioassay tests.

3.7.4 TNT Ditch Complex Soils.

The TNT ditch complex soils had only three locations (CC1, CC2, and FF3; of the 6 locations sampled) that contained TNT, but concentrations ranged up to 10,000 mg kg^{-1}. The analytical results are given in Table 10.

Sites CC1 and FF3 had a "highly" toxic response to all four of the bioassays. Site CC2, with a trace amount of TNT, had no positive responses to any of the bioassay tests.

Table 8. Results of HPLC Analysis from Area L2 Soils

Soil Sample	HPLC Analysis (μg/g soil, dry weight)*							
	RDX	HMX	TNT	TNB	2,4-DNT	2,6-DNT	2-Amino-DNT	4-Amino-DNT
K1	0**	0	19990	15	40	0	BCD	BCD
K2	0	0	519	12	8	BCD	BCD	BCD
K3	8	5	4594	200	0	0	0	0
K5	0	0	0	0	0	0	0	0
L1	BCD	BCD	4518	39	BCD	0	BCD	BCD
L2	BCD	12	1435	58	BCD	0	BCD	BCD
L3	157	BCD	355	52	0	11	0	0
L5	0	0	31	9	0	0	0	0
L6	0	0	0	0	0	0	0	0
M1	BCD	4	2417	7	BCD	BCD	BCD	BCD
M2	BCD	6	6025	161	13	8	BCD	BCD
M3	0	0	266	25	0	0	BCD	BCD
M5	0	0	0	0	0	0	0	0
M6	0	0	19	0	0	0	BCD	BCD
N1	3574	433	2655	145	BCD	BCD	BCD	BCD
N2	9	3054	1158	188	BCD	BCD	0	0
N3	0	0	0	0	0	0	0	0
N5	0	BCD	0	BCD	0	0	BCD	BCD
N6	7	26	0	BCD	BCD	0	0	BCD
O1	0	0	0	0	0	0	0	0
O2	0	0	0	0	0	0	0	0
P1	471	150	7847	309	28	32	22	BCD
P3	0	0	0	0	0	0	0	0
CA	0	0	0	0	0	0	0	0
CB	0	0	0	0	0	0	0	0
CC	0	0	0	0	0	0	0	0

*Values are a mean of 2 replicates. Values rounded to whole numbers.
**A zero value (0) corresponds to a "none detected" level. "BCD" indicates a concentration of less than the criterion of detection (trace concentration).

3.7.5 Lead Azide Soils.

No detectable levels of munitions or munition by-products were found for the three samples (GG2, HH4, and II4) analyzed.

3.7.6 Group 61 Soils.

Analysis of Group 61 soils (2 samples: JJ3 & JJ7) contained no detectable levels of munitions or munition by-products.

Table 9. Results of HPLC Analysis from Group 1 Soils

Soil Sample	HPLC Analysis (μg/g soil, dry weight)*							
	RDX	HMX	TNT	TNB	2,4-DNT	2,6-DNT	2-Amino-DNT	4-Amino-DNT
A2	0**	0	655	22	0	0	BCD	BCD
A2'	0	0	4207	25	BCD	0	BCD	BCD
A3	0	0	0	0	BCD	0	0	0
A4	0	0	BCD	0	0	0	0	0
A5	0	0	0	0	0	0	0	0
A6	0	0	0	0	0	0	0	0
B4	0	0	0	0	0	0	0	0
B5	0	0	0	0	0	0	0	0
C1	0	0	6.5	8	0	0	BCD	BCD
D1	0	0	1066	17	BCD	0	BCD	BCD
E1	1509	315	7114	49	7	0	19	20
E2	3101	572	15	BCD	0	0	BCD	BCD
E3	0	0	0	0	0	0	0	0
G1	0	0	9123	28	22	0	BCD	BCD
G2	0	0	2092	30	BCD	0	BCD	BCD
H2	0	0	0	0	0	0	0	0
I1	80	0	10679	23	19	0	BCD	BCD
I2	25	24	87082	24	117	BCD	BCD	BCD
I3	0	0	17	0	0	0	0	0

*Values are a mean of 2 replicates. Values rounded to whole numbers.
**A zero value (0) corresponds to a "none detected" level. "BCD" indicates a concentration of less than the criterion of detection (trace concentration).

Table 10. Results of HPLC Analysis from TNT Ditch Complex Soils

Soil Sample	HPLC Analysis (μg/g soil, dry weight)*							
	RDX	HMX	TNT	TNB	2,4-DNT	2,6-DNT	2-Amino-DNT	4-Amino-DNT
BB2	0**	0	0	0	0	0	0	0
CC1	0	0	10138	67	10	8	35	34
CC2	0	0	BCD	0	0	0	0	0
CC3	0	0	0	0	0	0	0	0
DD5	0	0	0	0	0	0	0	0
FF3	0	0	694	11	49	0	30	12

*Values are a mean of 2 replicates. Values rounded to whole numbers.
**A zero value (0) corresponds to a "none detected" level. "BCD" indicates a concentration of less than the criterion of detection (trace concentration).

3.8 Regression Analyses.

Data from Sites A2, L2, and Group 1 were selected to compare the relationship between results of the toxicity tests and TNT concentrations found in the soil. These sites showed the greatest degree of variability in the toxicity levels and the highest concentration of TNT.

3.8.1 Area 2.

Linear regression curves[6] of mean plant heights, mean earthworm final weights (adjusted for the initial weights), and Microtox EC_{50} (percent) versus log TNT concentrations are shown in Figures 7-10. The coefficients of determination (R^2) for radish, cucumber, earthworm, and Microtox assays were 0.857, 0.925, 0.683, and 0.856, respectively. All of the results were statistically significant at $p < 0.05$.

3.8.2 Area L2.

Linear regression curves of mean plant heights, mean earthworm final weights (adjusted for the initial weights), and Microtox EC_{50} (percent) versus log TNT concentrations are shown in Figures 11-14. The R^2 values for radish, cucumber, earthworm, and Microtox assays were 0.749, 0.834, 0.900, and 0.657, respectively. All results were statistically significant at $p < 0.05$.

3.8.3 Group 1.

Linear regression curves of mean plant heights, mean earthworm final weights (adjusted for the initial weights), and Microtox EC_{50} (percent) versus log TNT concentrations are shown in Figures 15-18. The R^2 values for radish, cucumber, earthworm, and Microtox assays were 0.734, 0.857, 0.745, and 0.566, respectively. The data point at 100% Microtox EC_{50} and 0 mg kg^{-1} TNT (Figure 18) represents seven sampling sites. All results were statistically significant at $p < 0.05$.

4. DISCUSSION

Data from the phytotoxicity, earthworm toxicity, Microtox test, HPLC analyses, and regression analysis were correlated to determine the extent of contamination at the six sampling sites that exhibited varying levels of toxicity.

Toxicity testing resulted in the identification of Areas A2, L2, and Group 1 as the sites with the highest levels of toxicity. Sampling locations, which had produced a toxic response to any of the bioassays, were chosen for further determinations using HPLC analysis. The analyses of these samples (along with appropriate controls and blanks) confirmed contamination by TNT in samples that showed a highly toxic response to one or more of the bioassays. Regression analyses of these three sites have shown a strong relationship between the bioassays and soil TNT levels. Furthermore, an analysis of the scatter plots (Figures 7-18) indicated boundary sectors marking the extent of contamination and level(s) of toxicity within each site.

The most toxic section of Area 2 was on an east-west transect between Q2 and Q4 (Figure 1). Significant ($p < 0.05$) reductions in plant heights, earthworm weights, and Microtox percent EC_{50}s occurred in Samples Q2 and Q4 (Figures 7-10). However, moderate toxicity occurred at Sites S6 and R3, although no TNT was found at either location. Sample S6 soil had a moderately toxic effect on earthworms. The cause of these toxicities will require further study but may be due to a high concentration of heavy metals (metals have been shown to produce a negative impact on

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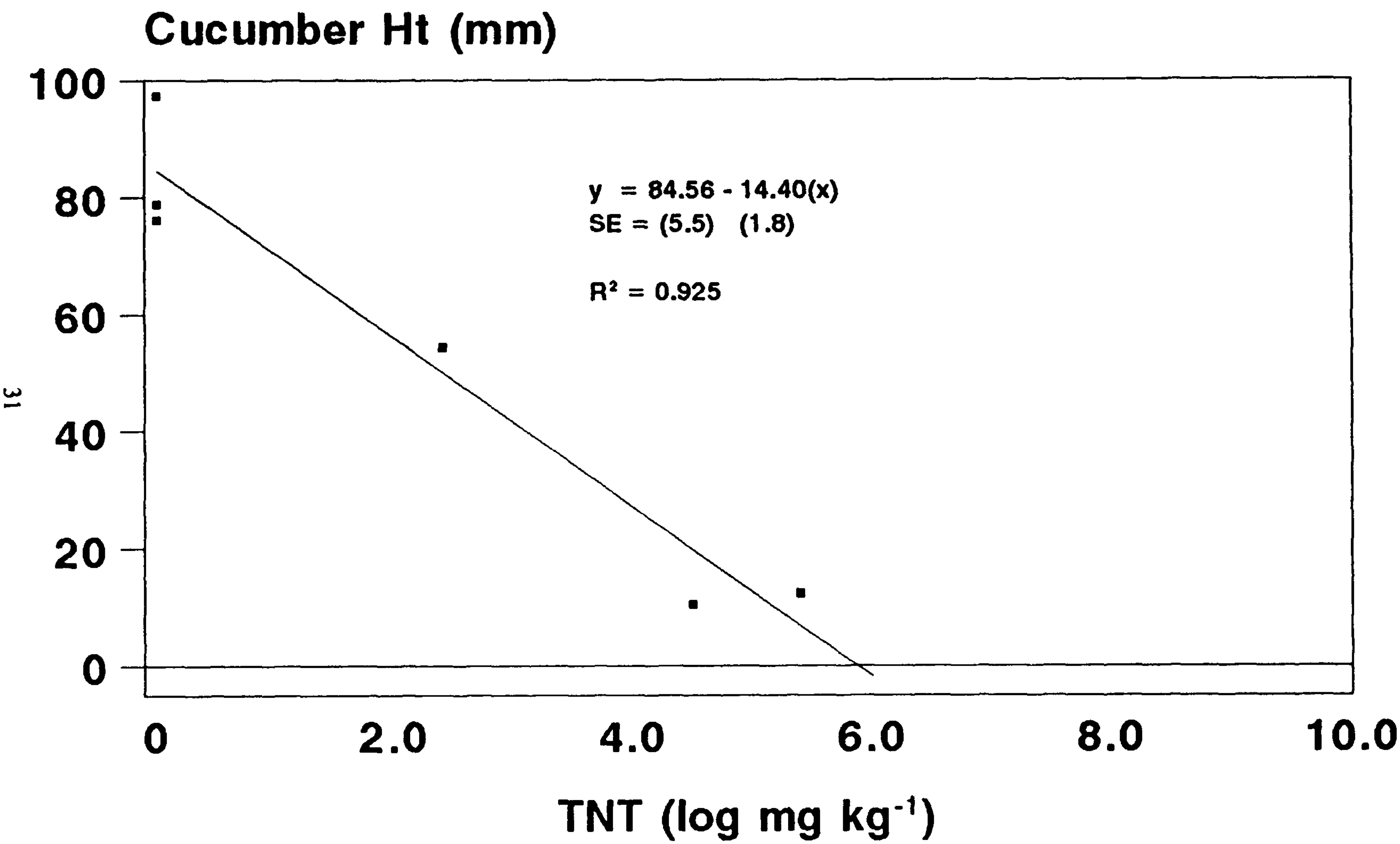

Figure 7. Area 2 - Cucumber Height vs TNT

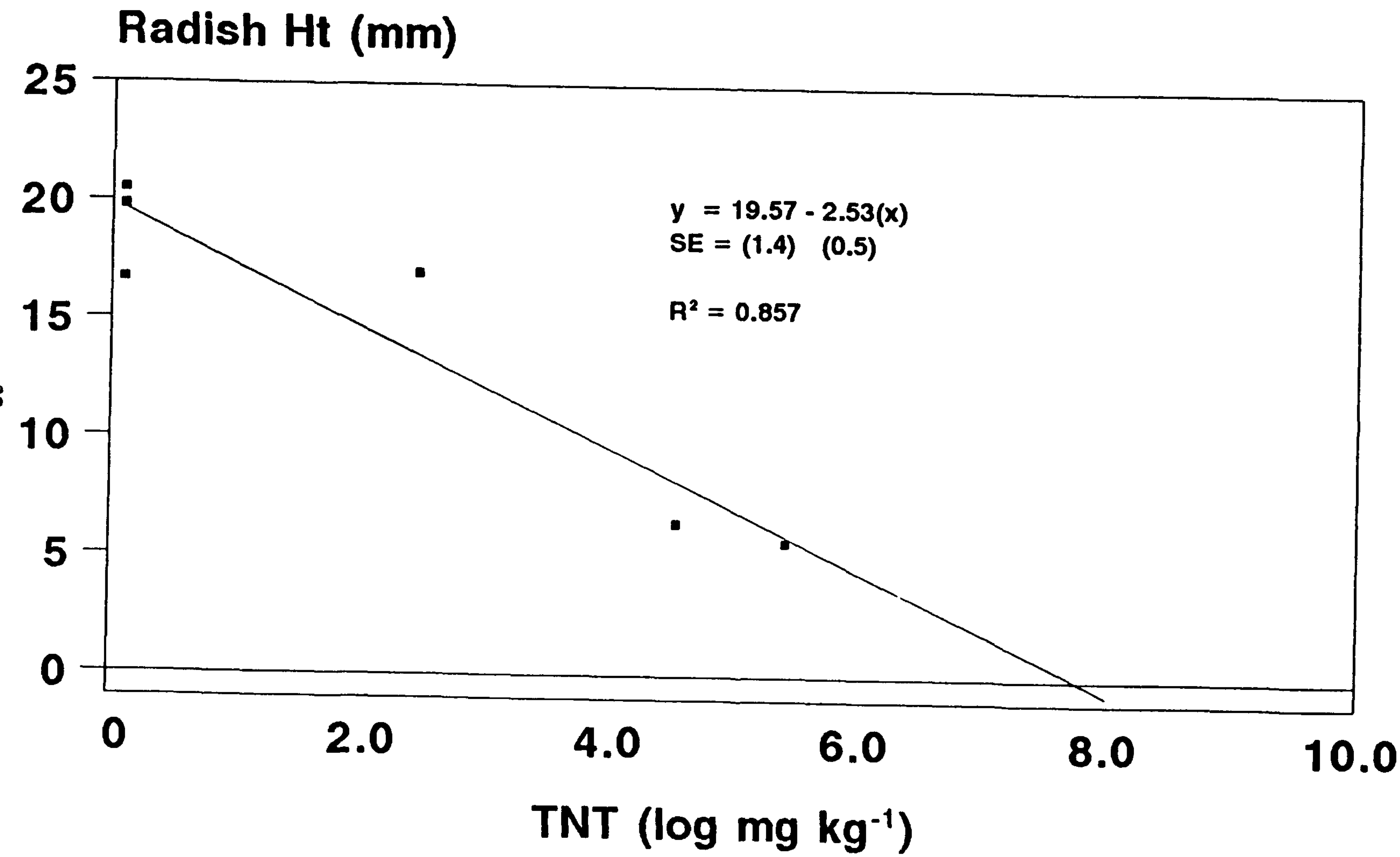

Figure 8. Area 2 - Radish Weight vs TNT

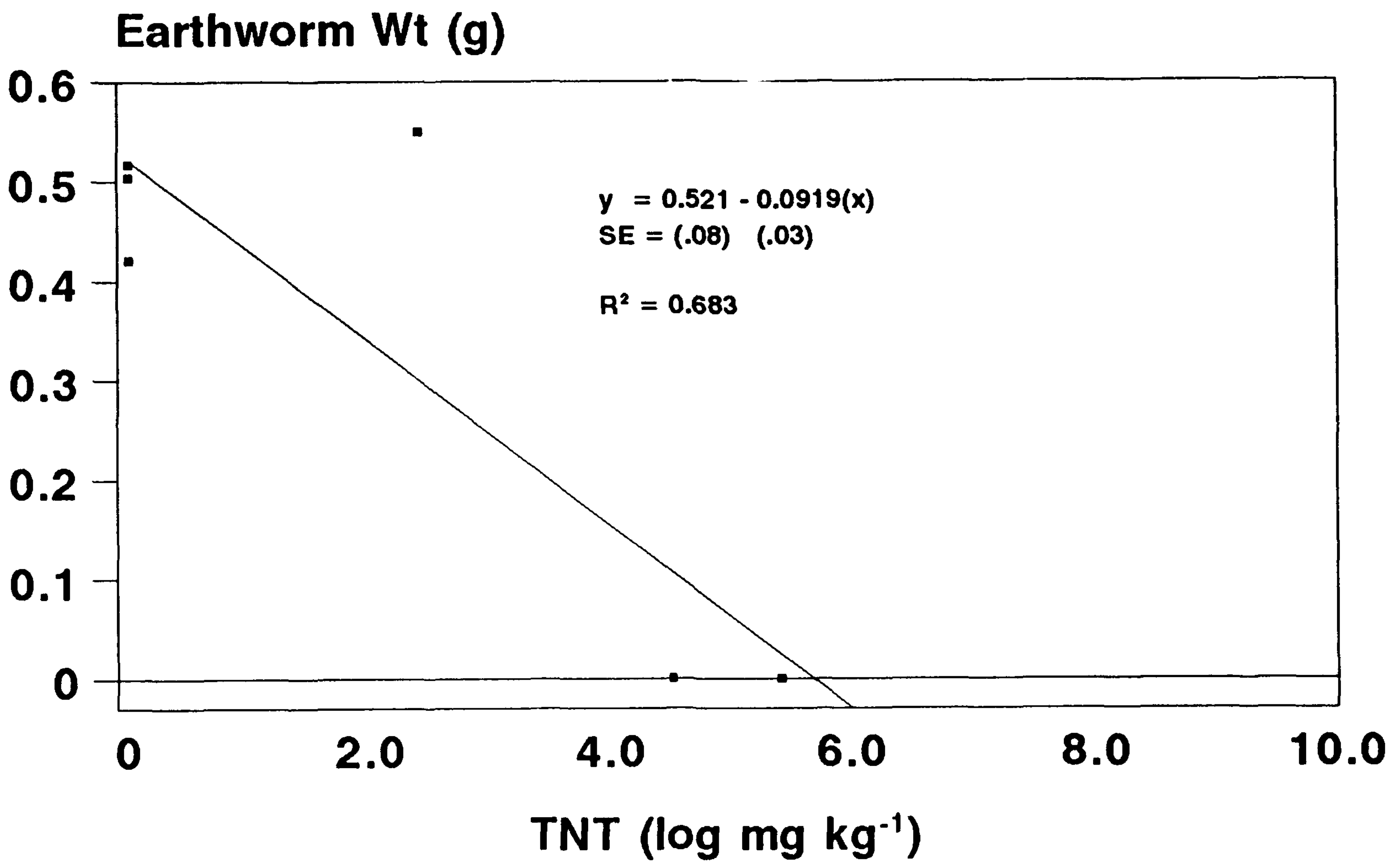

Figure 9. Area 2 - Earthworm Weight vs TNT

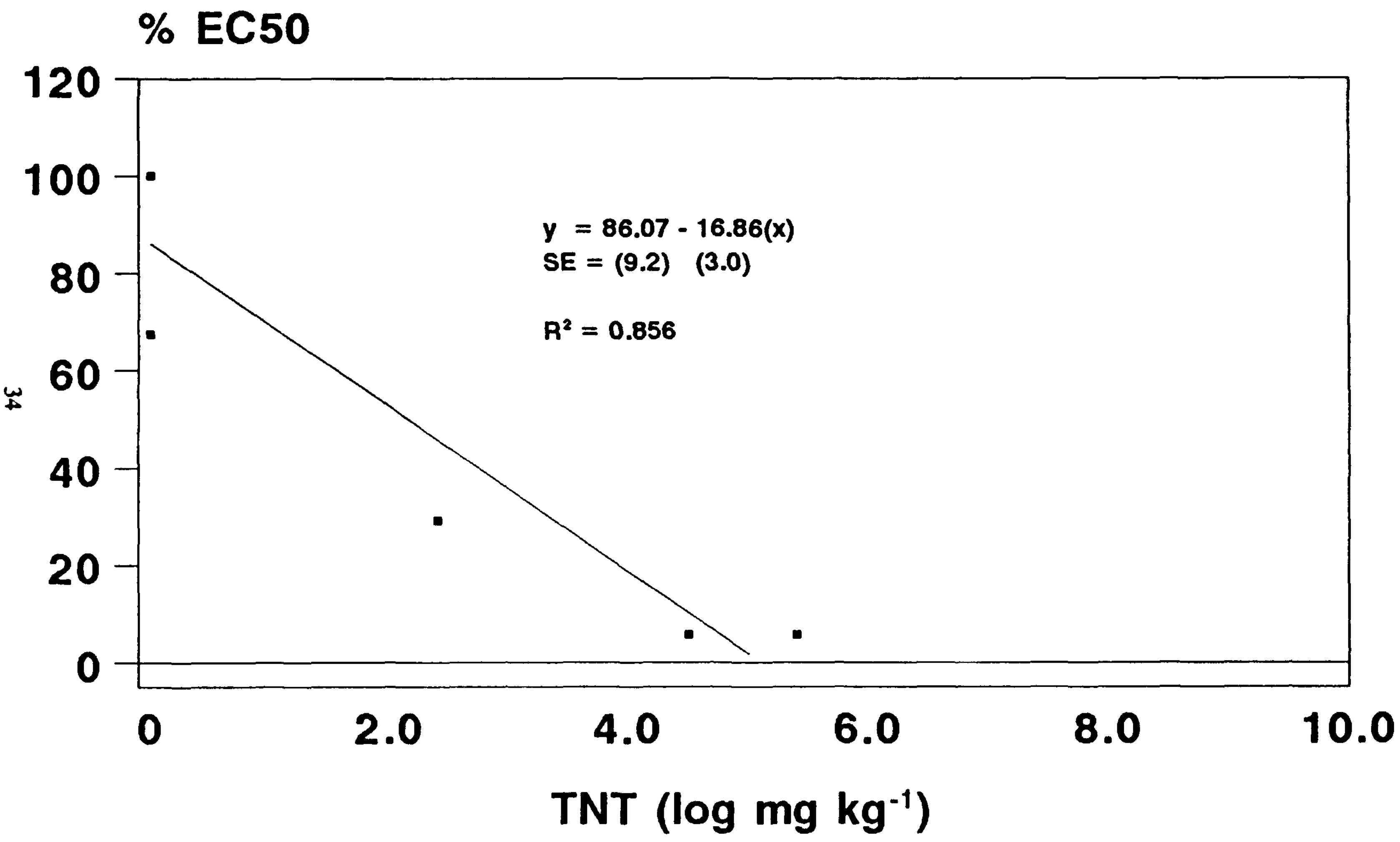

Figure 10. Area 2 - Microtox Percent EC_{50} vs TNT

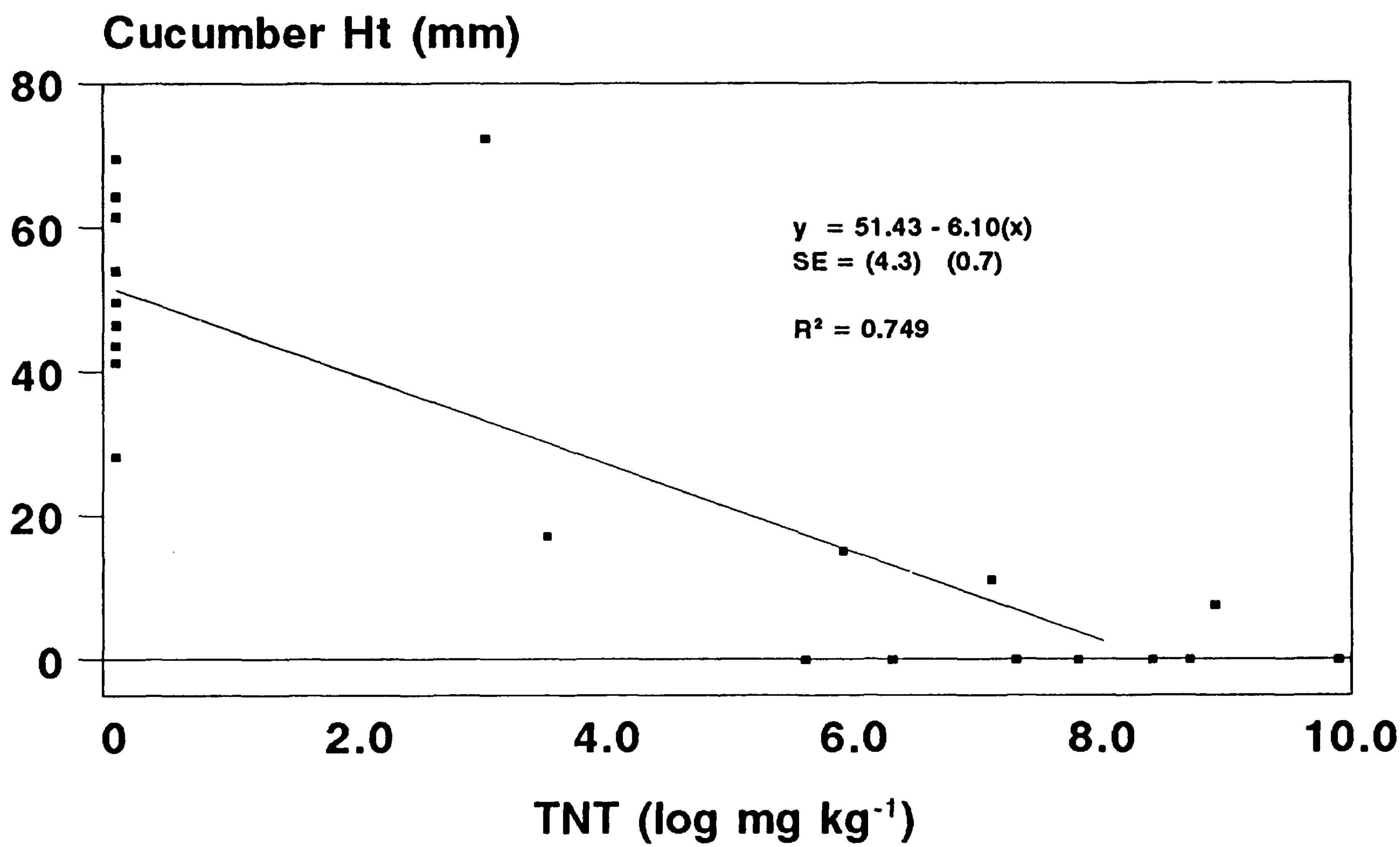

Figure 11. Area L2 - Cucumber Height vs TNT

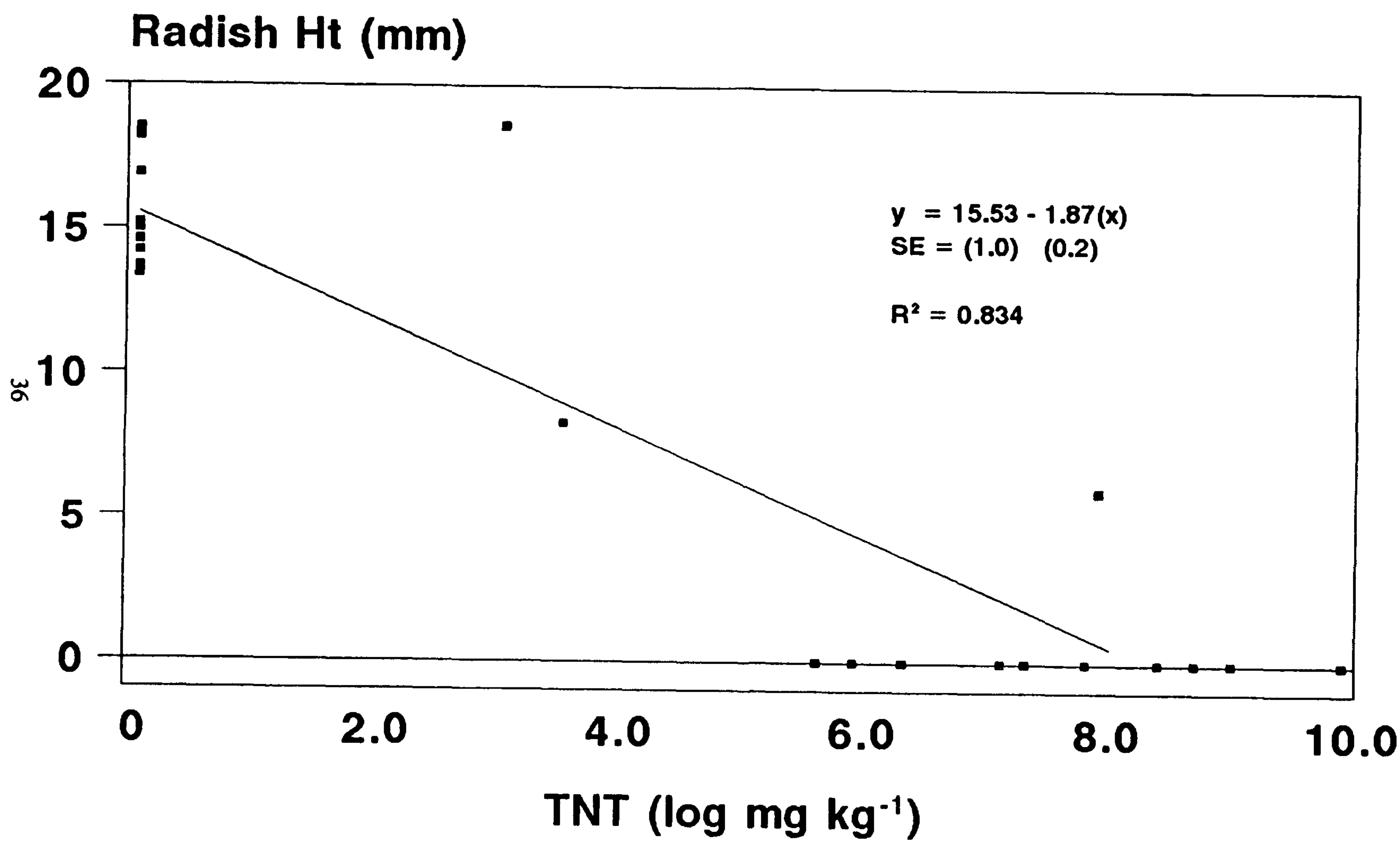

Figure 12. Area L2 - Radish Height vs TNT

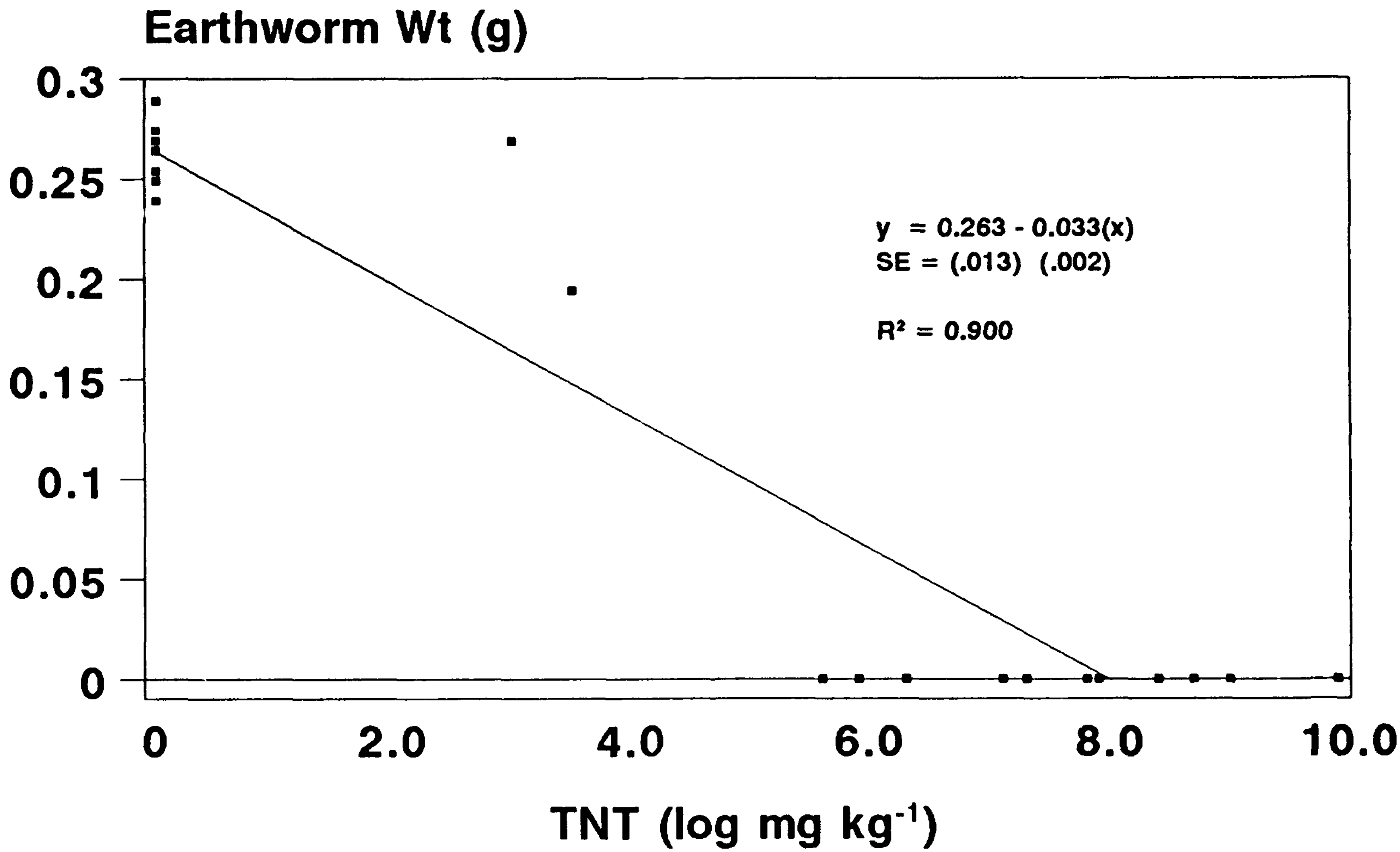

Figure 13. Area L2 - Earthworm Weight vs TNT

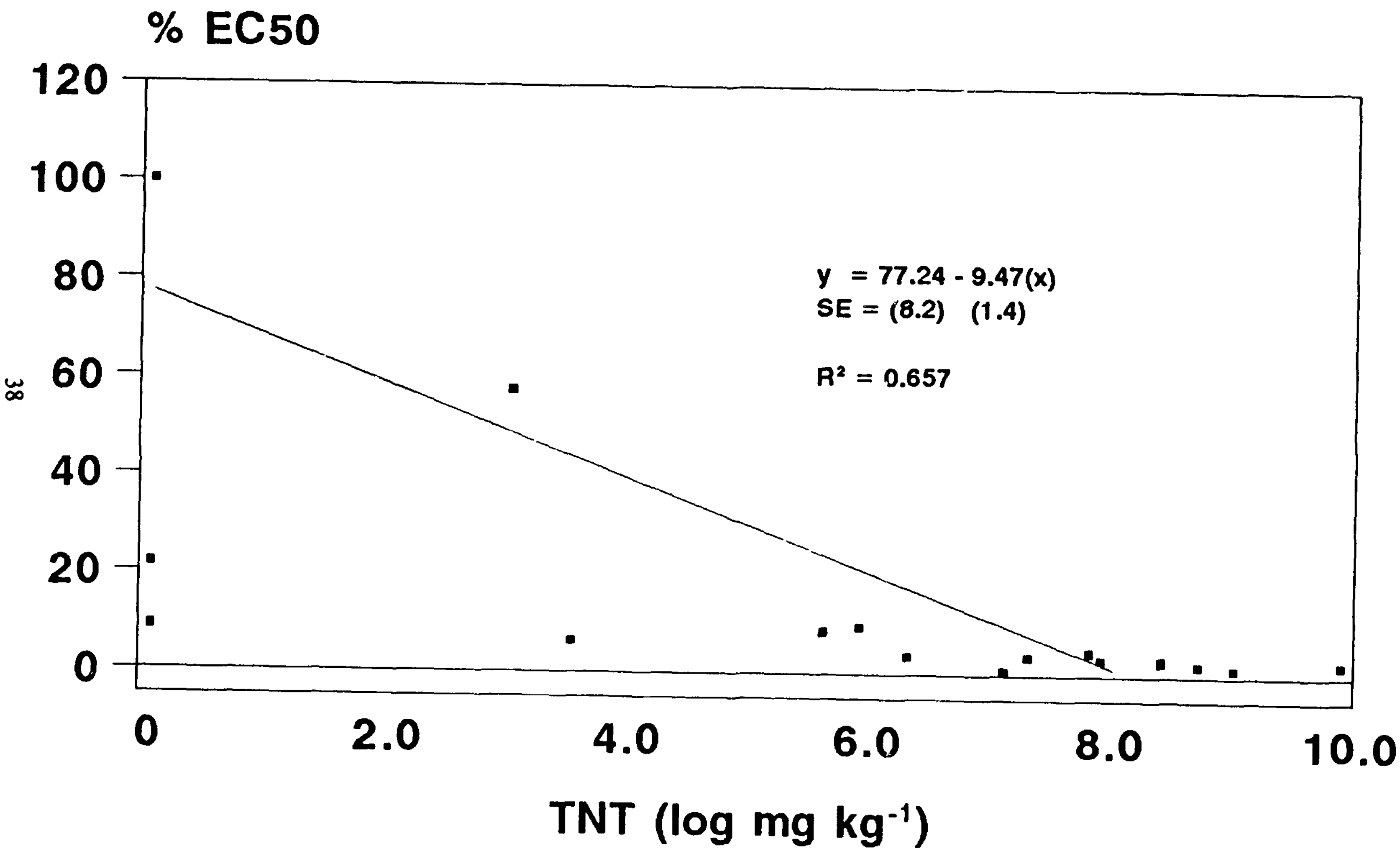

Figure 14. Area L2 - Microtox Percent EC_{50} vs TNT

Figure 14.

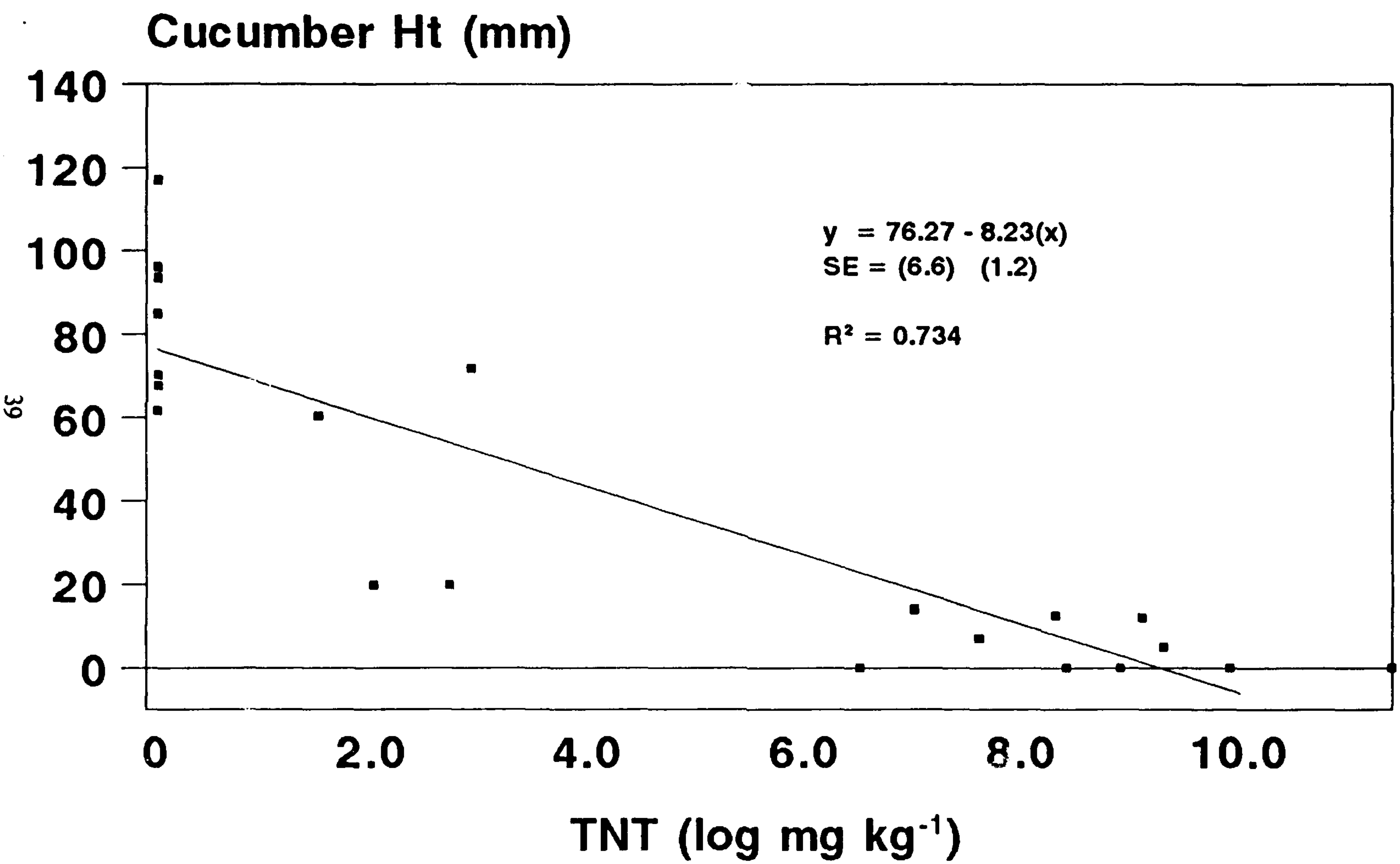

Figure 15. Group 1 - Cucumber Height vs TNT

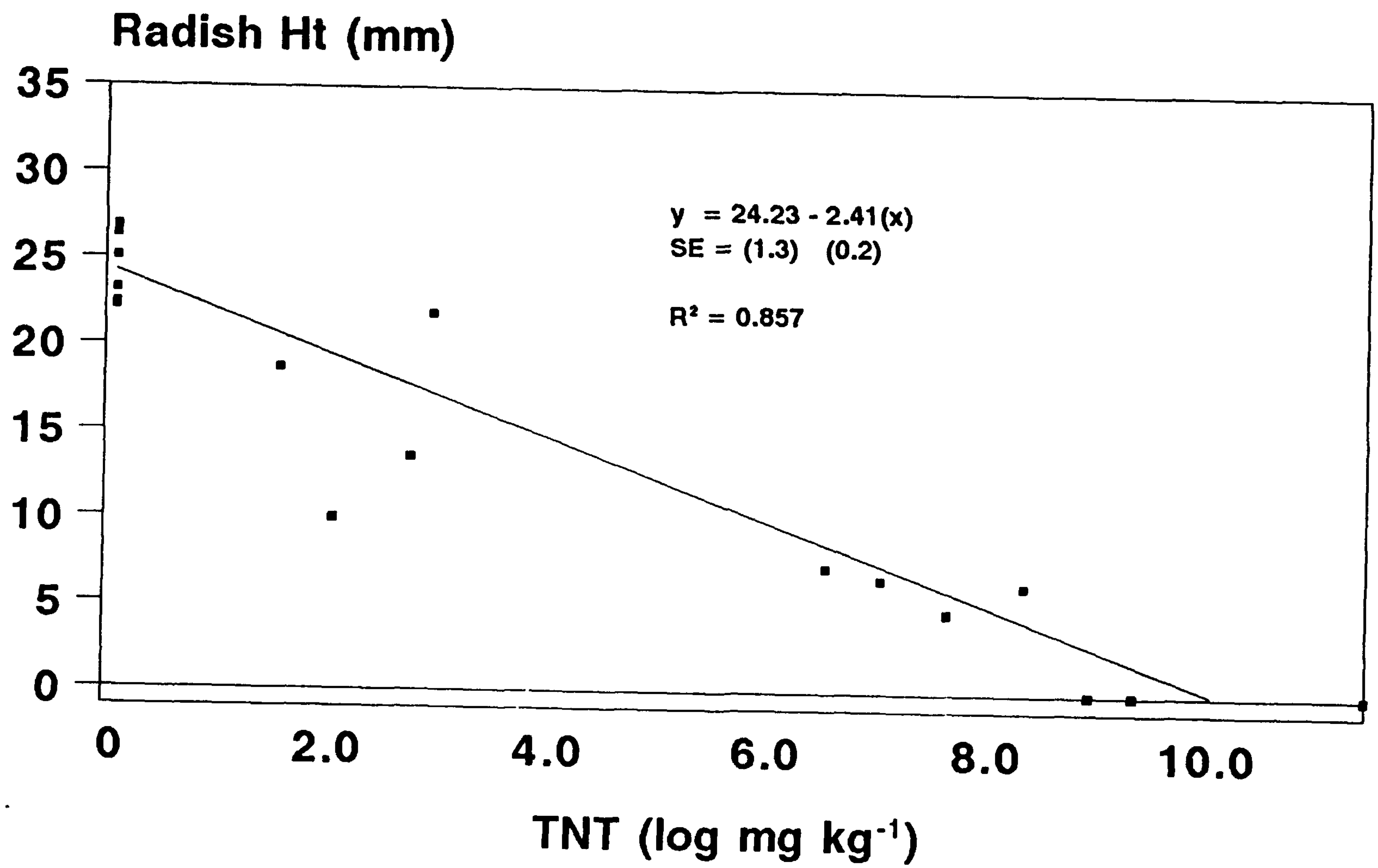

Figure 16. Group 1 - Radish Height vs TNT

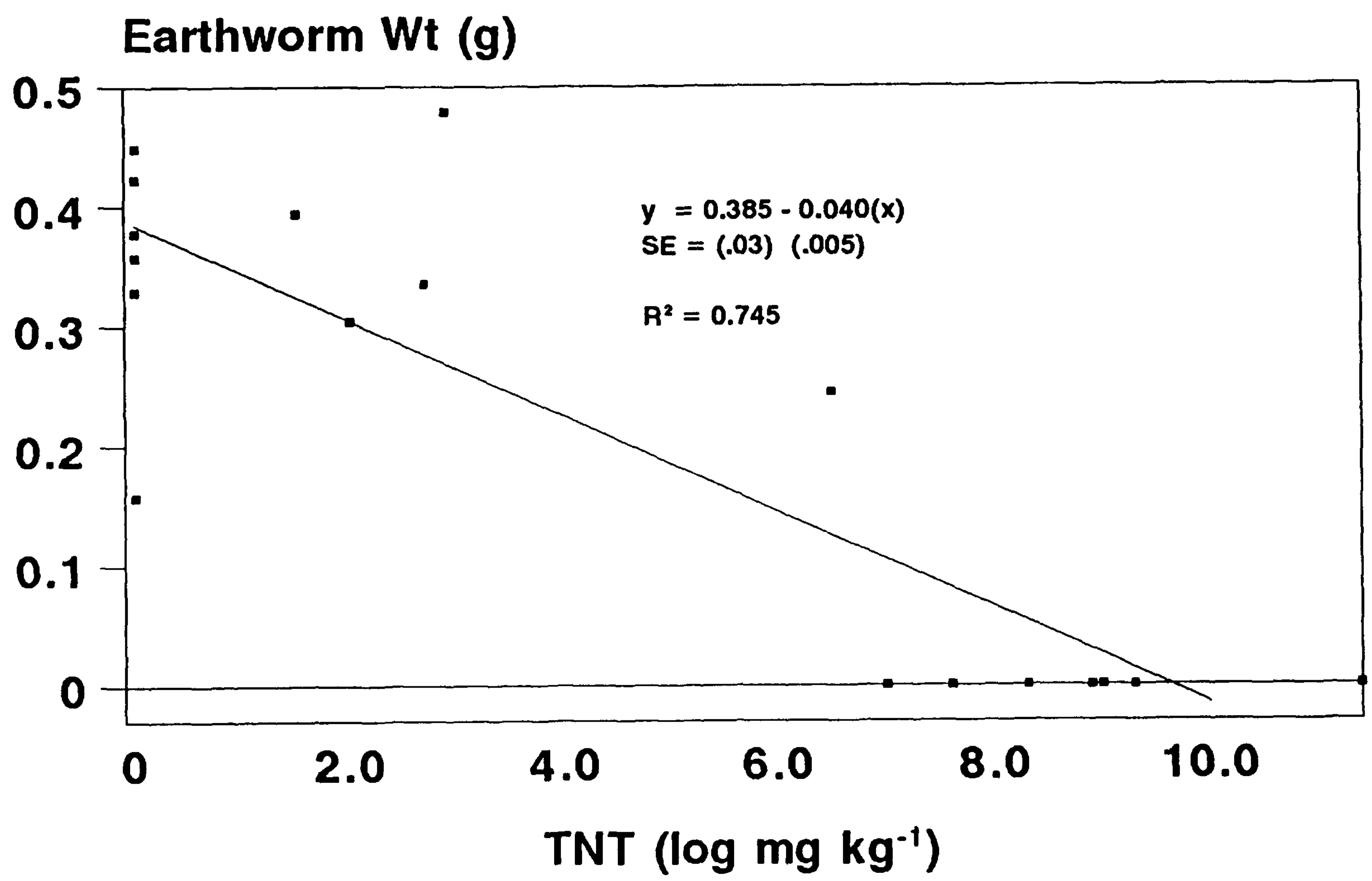

Figure 17. Group 1 - Earthworm Weight vs TNT

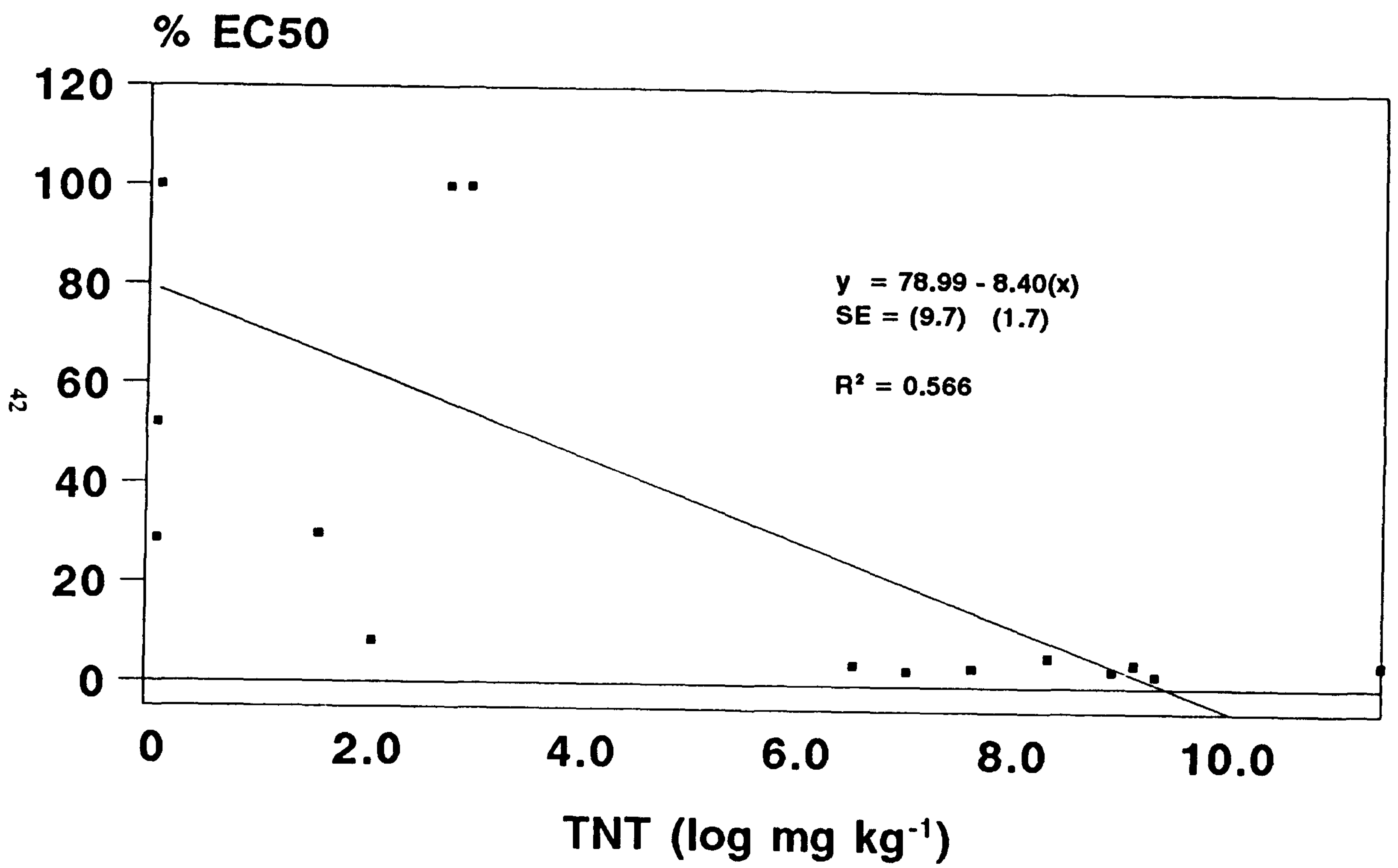

Figure 18. Group 1 - Microtox Percent EC_{50} vs TNT

earthworms.[12] Sample R3 soil (R3 is located outside of the burning ground) produced moderate toxicity in the Microtox assay, thus suggesting that a potentially toxic material may be present. Elevated (above background) levels of explosives and metals that were found in an earlier soil sampling study included TNT, 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 2-nitrotoluene (NT), 1,3,5-tri-nitrobenzene (TNB), As, Cr, Fe, Pb, Mn, and Ba.[11] Additional toxicity testing and chemical analyses including determination of the concentrations of heavy metals should beconducted to determine the extent of contamination, which would better delineate the areas required for remediation.

Area L2 has a fairly well-defined highly toxic section in the central portion. Radiating out from this central portion, toxicity levels decreased along the east-west plane. Significant ($p < 0.05$) reductions in plant heights, earthworm weights, and Microtox percent EC_{50}s occurred in Sample L5 and all samples containing greater concentrations of TNT (Figures 11-14). Samples N5 and N6 had highly toxic results for the Microtox test, although no TNT was found. Sample N6 soil also produced a moderately toxic effect on cucumber plants. The USATHAMA[11] remedial investigation (RI) indicated that analyses of soil from this area to determine the presence of explosives and metals has not been done. Additional samples have to be taken to determine the definitive area of contamination, especially along the east-west transect.

Group 1 soils close to the buildings were found to be moderately to highly toxic. However, location D1 also proved to be highly toxic in all bioassays. Significant ($p < 0.05$) reductions in plant heights, earthworm weights, and Microtox percent EC_{50}s occurred in Sample A2 and all samples with TNT concentrations $\geq$ 90 mg kg^{-1} (Figures 15-18). Plant heights were also significantly ($p < 0.05$) reduced in Sample E2, which contained only a small amount of TNT, but no toxicity was found in the earthworm or Microtox tests. Sample E2 may contain a phytotoxic chemical [e.g., cyclotrimethylene-trinitramine (RDX)] that affects plants but not earthworms or Microtox bacteria. Sample A5 was toxic to earthworms with significant ($p < 0.05$) weight reduction and only 10% survival but was not toxic in the other assays. Sample A5 may contain a high concentration of heavy metal(s) to which earthworms are more sensitive. An earlier RI of Group 3 (Site L9) reported soils samples with TNT levels at 180,000 mg kg^{-1}, 2,4-DNT at 25,000 mg kg^{-1}, 2,6-DNT at 20,000 mg kg^{-1}, NT at 50,000 mg kg^{-1}, RDX at 22,000 mg kg^{-1}, cyclotetramethylene-tetra-nitramine (HMX) at 690 mg kg^{-1}, and TNB at 92 mg kg^{-1}.[13] The HPLC analyses determined that most of these contaminants are present in Group 1 soils.

Few data exist to explain TNT fate in soil, bioavailability, and effects on terrestrial plants and ecosystems. Cataldo et al.[14] found that TNT absorption by plants was inversely related to the amount of organic matter present in the soil. Therefore, plants grown in different soil types, containing varying amounts of organic matter would absorb different amounts of TNT. Palazzo and Leggett[15] found that shoot and root growth of yellow nutsedge (hydroponically grown) was inhibited at 5 mg L^{-1} TNT. Our plant studies have shown that growth reduction, germination rates, and survivability of plants grown in field soils can be used to define toxic areas at JAAP.

The no observable effects level (NOEL) and the lowest observable effects level (LOEL) of soil contaminants are important for risk assessment and remediation of toxic sites. Scatter plot analyses of toxicity assay results indicated that the NOEL and LOEL of TNT ranged from approximately 30 to 90 mg kg^{-1} (Figures 7-18). Lethal effects and growth reduction of plants and earthworms and reduced Microtox percent EC_{50}s (<70%) began in this range. In general, toxicity intensified as TNT concentrations increased. However, Samples BB2 and CC3 from the TNT ditch complex; Samples A3, A5, B5, and E2 from Group 1; Samples N5, N6, and O1 from Area L2; and Samples R3 and S6 from Area 2 had no reportable TNT levels. These samples, however, did have a deleterious response to one or more of the bioassays. This may be due to contamination by other types of munition wastes and/or by heavy metals at the site. Conversely, all of the assays had a moderate or high response to samples containing TNT concentrations $\geq$30-90 mg kg^{-1}. The TNT was used as an indicator of soil contamination in this study. Other contaminants (e.g., TNT degradation products, other explosives such as RDX and HMX, and heavy metals) may have had an affect on the bioassays and, consequently, on the NOEL and LOEL.

Elevated (above background) levels of explosives and metals found during the remedial investigation included RDX, HMX, 2,4-DNT, 2,6-DNT, NT, TNB, 1,3-dinitrobenzene (DNB), As, Cr, Cu, Fe, Pb, Mn, Ba, and Hg at Area 2, TNT Ditch Complex, and Lead Azide (sites on the manufacturing side of the plant).[11] Screening for explosives from selected sampling locations has detected appreciable levels of RDX, HMX, TNB, 2,4-DNT, 2,6-DNT, 2-amino DNT, and 4-amino DNT in this study. These explosives may have increased the toxicity of the soils. Complete analyses is needed to identify and quantify all potentially toxic contaminants present in these soils. Statistical comparisons of contaminant concentrations and bioassays results are required to more precisely determine NOEL's, LOEL's, EC_{50}s, and the extent of contaminated areas. Selection for additional analyses should be based on the presence of elevated levels found in the RI and/or a significant toxic response to one or more of the bioassays.

This study has shown the importance of using multiple bioassays for examining National Priority List sites. Multiple bioassay screening uses different trophic levels that can help determine areas within a site where chemical analyses should be performed. For example, a particular contaminant may not produce a toxic response in one organisms but may cause toxicity in another organism. Therefore, screening with bioassays containing different trophic levels, as implemented in this study, can help to identify sites that need further investigation.

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APPENDIX A

PLANT DATA
Heights of Cucumber and Radish Plants Grown in JAAP Soils

Table A-1. Heights (mm) of Cucumbers Plants on Day 15 Grown in Area 2 Soils

Plant No.	Q1	Q2	Q3	Q4	Q5	R2	R3	R4	R5	R6	S2	S3	S4	S5	S6	CA
	Plant Heights															
1.	61	10	67	11	41	66	81	49	70	55	86	53	45	40	75	65
2.	60	9	105	12	46	63	99	47	65	70	87	81	51	40	74	59
3.	50	12	116	11	51	53	75	49	80	57	86	64	48	37	81	71
4.	70	12	103	9	42	68	100	70	65	65	110	55	46	54	90	73
5.	40	9	101	15	51	70	78	65	44	91	103	70	45	55	66	87
6.	51	-	115	16	52	75	84	59	72	80	102	62	47	45	73	76
7.	48	-	80	-	48	75	74	54	83	78	99	74	45	48	60	64
8.	39	-	104	-	42	76	63	72	73	90	80	74	68	45	88	73
9.	70	-	80	-	44	68	89	47	90	72	105	85	40	50	70	76
10.	55	-	102	-	45	87	46	75	65	65	102	52	66	46	85	68

Table A-2. Heights (mm) of Radish Plants on Day 15 Grown in Area 2 Soils

Plant No.	Q1	Q2	Q3	Q4	Q5	R2	R3	R4	R5	R6	S2	S3	S4	S5	S6	CA
	Plant Heights															
1.	18	6	20	7	23	19	14	19	20	16	21	16	21	19	15	19
2.	16	10	24	5	22	14	27	19	18	15	25	20	23	16	15	15
3.	17	7	16	9	15	16	16	21	21	17	21	20	19	14	16	17
4.	17	5	20	6	22	21	11	16	16	18	26	17	16	10	20	16
5.	15	4	21	5	20	16	30	25	17	23	20	36	22	19	18	20
6.	14	6	18	2	18	16	25	20	20	19	15	26	24	19	19	20
7.	19	6	19	-	15	16	26	20	18	19	20	30	26	17	16	20
8.	19	8	14	-	15	20	21	17	20	15	19	25	16	12	17	21
9.	15	-	25	-	12	17	14	21	21	21	25	20	20	14	15	18
10.	20	-	21	-	18	16	21	22	18	20	21	22	20	16	16	20

Table A-3. Heights (mm) of Cucumbers Plants on Day 15 Grown in Area L2 Soils

Plant No.	K1	K2	K3	K4	K5	L1	L2	L3	L4	L5	L6	M1	M2	M3	M4
	Soils (Plant Heights)														
1.	-	-	-	71	45	-	-	15	71	11	41	-	-	-	62
2.	-	-	-	73	40	-	-	-	74	26	50	-	-	-	70
3.	-	-	-	97	57	-	-	-	84	15	42	-	-	-	81
4.	-	-	-	88	46	-	-	-	77	19	41	-	-	-	79
5.	-	-	-	76	41	-	-	-	90	15	41	-	-	-	69
6.	-	-	-	61	42	-	-	-	100	11	40	-	-	-	80
7.	-	-	-	60	46	-	-	-	94	16	44	-	-	-	89
8.	-	-	-	74	51	-	-	-	90	18	43	-	-	-	80
9.	-	-	-	85	36	-	-	-	75	20	36	-	-	-	56
10.	-	-	-	91	32	-	-	-	68	20	34	-	-	-	66

M5	M6	M7	N1	N2	N3	N4	N5	N6	01	02	03	P1	P2	P3	P4	P5
Soils (Plant Heights)																
54	56	33	-	11	60	93	77	21	51	41	41	10	62	25	78	56
71	60	64	-	-	55	83	62	34	53	48	50	5	75	38	80	70
88	77	55	-	-	70	81	51	35	81	56	55	-	71	42	85	70
78	73	61	-	-	74	104	40	20	55	50	41	-	66	41	74	70
73	75	65	-	-	65	86	33	26	51	47	56	-	65	46	100	75
80	85	60	-	-	53	88	67	30	60	48	40	-	70	55	65	71
56	85	54	-	-	65	76	61	30	78	54	41	-	45	64	81	45
59	84	70	-	-	52	115	51	26	71	55	54	-	40	58	72	46
81	66	81	-	-	61	92	49	34	78	41	51	-	25	50	81	70
55	62	82	-	-	60	96	49	25	65	56	57	-	60	46	79	66

P6	CA1	CA2
Soils (Plant Heights)		
56	47	61
62	50	70
74	35	55
66	60	70
76	66	51
59	70	49
66	52	70
68	55	64
55	53	60
54	47	60

Table A-4. Heights (mm) of Radish Plants on Day 15 Grown in Area L2 Soils

Plant No.	K1	K2	K3	K4	K5	L1	L2	L3	L4	L5	L6	M1	M2	M3	M4
1.	-	-	-	23	15	-	-	-	15	11	13	-	-	-	11
2.	-	-	-	25	20	-	-	-	15	14	6	-	-	-	17
3.	-	-	-	20	21	-	-	-	18	15	14	-	-	-	20
4.	-	-	-	20	16	-	-	-	24	8	15	-	-	-	15
5.	-	-	-	20	6	-	-	-	10	2	12	-	-	-	18
6.	-	-	-	21	10	-	-	-	15	6	13	-	-	-	18
7.	-	-	-	15	14	-	-	-	21	6	15	-	-	-	15
8.	-	-	-	14	9	-	-	-	16	4	14	-	-	-	16
9.	-	-	-	21	20	-	-	-	16	-	16	-	-	-	21
10.	-	-	-	23	11	-	-	-	19	-	16	-	-	-	10

M5	M6	M7	N1	N2	N3	N4	N5	N6	O1	O2	O3	P1	P2	P3
21	20	16	6	-	14	21	17	14	19	11	10	-	18	18
18	16	19	-	-	11	20	15	17	15	16	11	-	15	19
15	22	20	-	-	12	19	15	20	20	15	13	-	16	16
20	17	17	-	-	18	15	11	15	12	19	15	-	18	20
20	15	15	-	-	19	25	14	11	10	11	14	-	12	21
14	24	11	-	-	19	18	15	15	11	16	15	-	15	15
14	15	15	-	-	16	24	11	20	15	15	15	-	16	16
25	21	10	-	-	12	20	13	17	16	12	14	-	17	20
20	15	21	-	-	14	24	10	15	19	15	15	-	16	17
18	21	18	-	-	15	25	16	15	15	16	10	-	12	20

P4	P5	P6	CA1	CA2
21	20	15	16	20
21	15	15	21	19
31	14	16	15	18
25	21	20	20	19
26	18	16	24	21
20	15	15	18	19
30	15	21	20	25
25	16	20	21	21
25	25	15	25	20
24	16	21	15	21

Table A-5. Heights (mm) of Cucumbers Plants on Day 14 Grown in Group 1 Soils

Plant No.	Soils A2	A2'	A3	A4	A5	A6	B4	B5	C1	C2	D1	D2	D3	E1	E2
	Plant Heights														
1.	-	10	55	59	96	82	74	115	22	82	11	51	111	-	21
2.	-	12	54	66	114	88	81	95	21	88	21	56	105	-	16
3.	-	14	61	55	125	80	60	80	16	117	10	62	116	-	22
4.	-	10	64	66	118	84	89	99	21	115	-	68	116	-	20
5.	-	18	61	65	129	83	67	90	19	112	-	75	114	-	17
6.	-	15	61	50	136	100	55	106	16	93	-	75	126	-	22
7.	-	10	65	64	134	101	83	106	20	116	-	71	121	-	23
8.	-	11	56	65	115	105	67	96	22	109	-	73	131	-	19
9.	-	-	74	55	98	102	60	90	20	101	-	68	116	-	18
10.	-	-	66	60	105	111	67	85	21	100	-	66	120	-	21

Soils E3	E4	E5	F1	F3	F4	G1	G2	H1	H2	H3	H4	I1	I2	I3
Plant Heights														
61	71	71	74	74	80	12	5	95	64	79	76	5	-	70
75	66	76	85	65	91	-	9	110	66	76	66	-	-	45
95	79	56	66	76	98	-	-	111	61	90	70	-	-	74
82	73	81	80	76	104	-	-	102	71	66	75	-	-	74
92	80	80	70	68	90	-	-	101	78	95	73	-	-	75
91	62	75	79	77	108	-	-	131	80	86	86	-	-	75
90	61	81	81	71	99	-	-	124	57	74	75	-	-	79
100	77	78	87	75	91	-	-	126	72	91	68	-	-	80
90	63	80	76	61	85	-	-	111	64	84	76	-	-	60
74	60	74	78	56	102	-	-	130	63	80	69	-	-	86

Soils J1	CB1	CB2
Plant Heights		
65	78	89
99	65	80
82	61	101
81	90	99
102	66	98
84	80	85
104	81	82
99	73	70
100	65	74
83	76	83

Table A-6. Heights (mm) of Radish Plants on Day 14 Grown in Group 1 Soils

Plant No.	A2	A2'	A3	A4	A5	A6	B4	B5	C1	C2	D1	D2	D3	E1	E2
	Plant Heights														
1.	11	6	19	15	26	27	20	20	9	36	12	25	49	4	10
2.	6	10	21	16	20	29	25	28	5	21	4	15	25	6	9
3.	5	4	31	20	29	32	20	20	10	25	5	25	20	5	11
4.	-	2	17	19	30	28	25	30	15	25	5	21	25	5	13
5.	-	8	25	21	30	35	26	31	5	31	10	25	35	5	20
6.	-	7	15	15	35	35	29	35	14	31	6	24	27	-	15
7.	-	9	26	20	21	39	21	25	12	35	5	25	28	-	17
8.	-	3	20	25	26	30	22	25	14	40	5	21	32	-	-
9.	-	10	25	14	30	39	20	30	5	29	7	22	35	-	-
10.	-	4	25	22	22	41	24	20	11	35	-	20	45	-	-

E3	E4	E5	F1	F3	F4	G1	G2	H1	H2	H3	H4	I1	I2	I3
Plant Heights														
25	14	30	21	20	31	4	5	31	37	30	21	-	-	26
30	24	20	25	31	25	4	5	40	21	22	25	-	-	20
26	19	24	26	26	19	5	7	40	26	24	27	-	-	21
16	18	23	19	30	27	9	4	25	25	21	22	-	-	24
24	19	29	28	31	25	6	5	30	30	17	31	-	-	26
21	20	20	30	25	25	-	5	35	20	25	32	-	-	21
15	20	21	34	26	25	-	2	44	25	22	25	-	-	19
21	15	24	31	26	20	-	-	38	22	25	29	-	-	22
20	15	16	19	31	21	-	-	20	21	15	20	-	-	25
24	20	26	35	23	22	-	-	35	24	20	21	-	-	15

J1	CB1	CB2
Plant Heights		
34	26	17
40	26	20
35	19	24
40	20	25
32	28	25
29	27	20
28	26	21
40	26	17
20	25	24
34	25	20

Table A-7. Heights (mm) of Cucumber Plants on Day 14 Grown in TNT Ditch Soils

Plant No.	AA1	AA2	AA3	AA4	AA5	AA6	BB1	BB2	BB3	BB4	BB5	CC1	CC2	CC3	CC4
	Soils														
	Plant Heights														
1.	115	90	105	96	70	99	95	110	98	70	87	-	75	72	110
2.	125	73	104	96	90	113	100	112	100	87	104	-	66	83	133
3.	108	80	80	100	96	79	98	105	87	85	86	-	72	87	95
4.	117	60	106	106	92	102	117	105	92	73	116	-	70	66	88
5.	116	58	112	116	120	112	60	119	109	76	110	-	50	70	103
6.	95	72	95	104	98	104	88	110	102	95	106	-	84	84	112
7.	114	85	105	99	87	109	110	82	87	100	119	-	50	93	110
8.	128	85	107	96	100	105	110	110	87	80	110	-	45	85	100
9.	115	86	106	100	110	114	110	126	80	80	107	-	73	80	115
10.	108	103	90	80	110	115	107	133	78	78	112	-	96	94	93

CC5	CC6	DD1	DD2	DD3	DD4	DD5	EE1	EE2	EE3	EE4	EE5	EE6	FF1	FF2
Soils														
Plant Heights														
93	93	91	117	84	70	74	127	96	30	80	100	105	145	60
99	80	96	130	70	93	94	130	94	65	86	84	100	130	70
88	93	100	114	73	100	90	120	76	53	100	97	80	140	60
98	97	106	135	100	120	104	110	97	75	95	106	101	139	70
90	103	118	153	90	120	100	119	87	72	107	113	115	112	75
97	97	116	124	68	100	109	140	98	78	89	105	115	120	80
86	81	115	144	93	90	117	103	90	60	104	100	95	83	94
115	87	115	133	86	112	101	112	80	70	110	28	88	145	74
120	100	105	130	94	130	110	129	80	85	107	103	89	108	28
83	78	101	130	95	135	98	125	100	80	67	105	107	130	86

FF3	FF4	CA	CB
Soils			
Plant Heights			
-	95	89	53
-	130	70	74
-	131	84	69
-	109	83	82
-	113	94	88
-	125	83	86
-	123	75	72
-	130	97	54
-	132	97	96
-	135	80	86

Table A-8. Heights (mm) of Radish Plants on Day 14 Grown in TNT Ditch Soils

	Soils														
Plant No.	AA1	AA2	AA3	AA4	AA5	AA6	BB1	BB2	BB3	BB4	BB5	CC1	CC2	CC3	CC4
	Plant Heights														
1.	22	20	15	30	25	25	29	30	15	15	30	6	22	33	21
2.	20	22	20	40	25	30	22	35	20	18	30	6	23	27	22
3.	20	21	22	20	25	30	22	36	18	15	17	11	26	22	38
4.	20	10	20	30	30	30	22	30	22	15	16	10	27	22	30
5.	25	25	13	35	30	23	30	22	25	15	25	8	30	33	20
6.	14	30	21	43	31	33	18	23	20	15	21	15	30	28	20
7.	15	21	26	32	23	31	20	16	20	16	30	-	25	30	26
8.	19	38	18	22	37	22	18	20	26	16	14	-	36	18	16
9.	27	17	20	26	32	20	31	16	21	18	19	-	16	22	23
10.	18	30	20	25	23	26	18	20	20	17	30	-	20	40	24

Soils														
CC5	CC6	DD1	DD2	DD3	DD4	DD5	EE1	EE2	EE3	EE4	EE5	EE6	FF1	FF2
Plant Heights														
35	17	26	22	15	12	30	22	17	12	15	21	30	40	20
27	18	20	20	18	27	43	30	25	34	15	17	20	40	25
20	22	26	21	11	24	18	25	27	28	16	22	12	30	20
43	15	20	22	12	20	40	25	19	10	22	16	17	38	27
26	22	17	20	17	38	30	32	20	20	23	27	21	37	10
39	14	21	32	25	20	40	30	20	13	29	21	17	27	30
28	19	22	20	16	21	32	32	18	23	22	15	25	30	18
27	27	32	16	15	20	25	30	25	20	25	19	18	28	19
26	13	25	12	23	15	25	28	22	26	18	16	16	23	20
32	17	23	15	18	18	24	32	36	26	28	18	27	26	41

Soils			
FF3	FF4	CA	CB
Plant Heights			
10	37	25	30
10	26	16	16
10	26	18	37
-	31	21	20
-	25	22	22
-	32	22	22
-	31	26	23
-	32	21	16
-	36	15	23
-	15	17	30

Table A-9. Heights (mm) of Cucumber Plants on Day 14 Grown in Lead Azide Soils

Plant No.	GG1	GG2	GG3	GG4	GG5	HH1	HH2	HH3	HH4	II1	II2	II4	II5
	Plant Heights												
1.	110	90	120	123	95	100	122	110	107	133	130	97	127
2.	125	95	110	122	87	112	113	130	110	145	123	98	121
3.	133	103	117	122	115	104	136	115	110	145	124	102	100
4.	115	133	131	108	105	110	115	127	122	123	127	115	130
5.	112	100	133	142	115	113	135	120	138	110	104	112	134
6.	133	120	120	153	120	102	123	111	137	130	120	126	153
7.	137	128	118	105	122	123	122	109	133	141	106	132	123
8.	152	122	108	132	115	124	120	128	94	130	142	126	140
9.	123	99	135	92	122	120	110	118	113	123	130	125	130
10.	110	90	130	110	120	110	106	115	113	122	130	122	150

Table A-10. Heights (mm) of Radish Plants on Day 14 Grown in Lead Azide Soils

Plant No.	GG1	GG2	GG3	GG4	GG5	HH1	HH2	HH3	HH4	II1	II2	II4	II5
	Plant Heights												
1.	15	22	22	15	26	23	20	32	18	20	32	23	29
2.	23	36	32	23	28	24	23	29	22	27	27	31	30
3.	26	37	37	32	30	34	25	30	32	25	23	26	27
4.	22	17	38	42	30	22	23	28	27	28	22	23	20
5.	21	25	18	20	25	19	21	32	30	33	26	22	35
6.	27	30	23	32	23	26	23	45	23	37	21	25	30
7.	22	25	22	30	30	28	30	35	18	18	25	23	25
8.	25	28	20	21	32	19	23	32	19	17	25	26	20
9.	25	24	28	18	20	27	24	23	25	25	22	27	25
10.	23	34	20	17	20	23	27	17	33	28	20	23	25

Table A-11. Heights (mm) of Cucumber Plants on Day 14 Grown in Group 61 Soils

Plant No.	Soils JJ1	JJ2	JJ3	JJ4	JJ5	JJ6	JJ7
	Plant Heights						
1.	135	115	109	115	145	95	81
2.	133	125	113	118	147	120	88
3.	123	110	115	105	140	119	81
4.	116	125	91	107	161	107	84
5.	130	134	122	95	155	113	100
6.	118	120	120	110	150	123	87
7.	125	110	127	114	156	105	92
8.	113	120	128	114	145	115	75
9.	118	110	125	118	130	115	72
10.	118	120	112	75	125	125	65

Table A-12. Heights (mm) of Radish Plants on Day 14 Grown in Group 61 Soils

Plant No.	Soils JJ1	JJ2	JJ3	JJ4	JJ5	JJ6	JJ7
	Plant Heights						
1.	35	30	37	24	18	30	24
2.	33	30	33	26	26	23	20
3.	26	43	24	27	15	22	35
4.	25	23	34	27	26	24	28
5.	27	30	29	29	42	32	18
6.	23	25	36	31	28	30	28
7.	23	27	34	25	33	33	37
8.	30	19	17	28	26	19	27
9.	26	34	33	25	32	33	17
10.	31	40	28	22	33	27	19

Blank

APPENDIX B

STATISTICAL DATA
Analysis of Variance (ANOVA) of Heights of Cucumber and Radish Plants Grown in JAAP Soils and Newman-Keuls Analysis of Treatment of Cucumber and Radish Plant Heights Grown in JAAP Soils

Table B-1. ANOVA of Plant Heights of Cucumbers Grown in Area 2 Soils

Soil:	Q1	Q2	Q3	Q4	Q5	R2	R3	R4	R5	R6	S2	S3
N:	10	5	10	6	10	10	10	10	10	10	10	10
Mean:	54.4	10.4	97.3	12.3	46.2	70.1	78.9	58.7	70.7	72.3	96.0	67.0
Std.Dev.:	10.9	1.5	16.2	2.7	4.1	9.0	16.2	11.0	12.6	12.5	10.2	11.7

Soil:	S4	S5	S6	CA
N:	10	10	10	10
Mean:	50.1	46.0	76.2	71.2
Std.Dev.:	9.3	6.0	9.7	7.8

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	82399.881	150		
Error:	15320.833	135	113.488	
Treatment:	67079.047	15	4471.936	39.40

Significant at $p < 0.0001$

Table B-2. ANOVA of Plant Heights of Radishes Grown in Area 2 Soils

Soil:	Q1	Q2	Q3	Q4	Q5	R2	R3	R4	R5	R6	S2	S3
N:	10	8	10	6	10	10	10	10	10	10	10	10
Mean:	17.0	6.5	19.8	5.7	18.0	17.1	20.5	20.0	18.9	18.3	21.3	23.2
Std.Dev.:	2.0	1.9	3.3	2.3	3.7	2.2	6.5	2.5	1.7	2.6	3.3	6.2

Soil:	S4	S5	S6	CA
N:	10	10	10	10
Mean:	21.7	15.6	16.7	18.6
Std.Dev.:	4.1	3.1	1.8	2.0

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	82399.881	150		
Error:	15320.833	135	113.488	
Treatment:	67079.047	15	4471.936	39.40

Significant at $p < 0.0001$

Table B-3. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in Area 2 Soils

Cucumber Plants				Radish Plants			
Soil	Grouping	Critical Range	# of Means	Soil	Grouping	Critical Range	# of Means
Q3	a	17.481	16	S3	a	5.503	16
S2	a	17.298	15	S4	ab	5.445	15
R3	b	17.100	14	S2	ab	5.383	14
S6	b	16.886	13	R3	abc	5.316	13
R6	bc	16.652	12	R4	abc	5.242	12
CA	bc	16.394	11	Q3	abc	5.161	11
R5	bc	16.107	10	R5	abc	5.070	10
R2	bc	15.783	9	CA	abc	4.969	9
S3	bc	15.414	8	R6	abc	4.853	8
R4	cd	14.985	7	Q5	bc	4.717	7
Q1	d	14.473	6	R2	bc	4.556	6
S4	d	13.842	5	Q1	bc	4.358	5
Q5	d	13.023	4	S6	bc	4.100	4
S5	d	11.864	3	S5	c	3.735	3
Q4	e	9.901	2	Q2	d	3.117	2
Q2	e			Q4	d		

Table B-4. ANOVA of Plant Heights of Cucumbers Grown in Area L2 Soils

Soil:	K1	K2	K3	K4	K5	L1	L2	L3	L4	L5	L6	M1
N:	-	-	-	10	10	-	-	1	10	10	10	-
Mean:	-	-	-	77.6	43.6	-	-	15.0	82.3	17.1	41.2	-
Std.Dev.:	-	-	-	12.4	7.2	-	-	-	10.8	4.5	4.3	-

Soil:	M2	M3	M4	M5	M6	M7	N1	N2	N3	N4	N5	N6
N:	-	-	10	10	10	10	-	1	10	10	10	10
Mean:	-	-	73.2	69.5	72.3	62.5	-	11.0	61.5	91.4	54.0	28.1
Std.Dev.:	-	-	10.2	12.5	10.8	14.1	-	-	7.2	11.5	13.0	5.4

Soil:	O1	O2	O3	P1	P2	P3	P4	P5	P6	CA1	CA2
N:	10	10	10	2	10	10	10	10	10	10	10
Mean:	64.3	49.6	48.6	7.5	57.9	46.5	79.5	63.9	63.6	53.5	61.0
Std.Dev.:	12.0	5.7	7.1	3.5	16.0	11.1	9.2	10.9	7.7	10.1	7.7

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	96796.615	233		
Error:	21163.000	208	101.745	
Treatment:	75633.615	25	3025.345	29.73

Significant at $p < 0.0001$

Table B-5. ANOVA of Plant Heights of Radishes Grown in Area L2 Soils

Soil:	K1	K2	K3	K4	K5	L1	L2	L3	L4	L5	L6	M1
N:	-	-	-	10	10	-	-	-	10	8	10	-
Mean:	-	-	-	20.2	14.2	-	-	-	16.9	8.3	13.4	-
Std.Dev.:	-	-	-	3.4	5.2	-	-	-	3.8	4.7	2.9	-

Soil:	M2	M3	M4	M5	M6	M7	N1	N2	N3	N4	N5	N6
N:	-	-	10	10	10	10	1	-	10	10	10	10
Mean:	-	-	16.1	18.5	18.6	16.2	6.0	-	15.0	21.1	13.7	16.9
Std.Dev.:	-	-	3.5	3.5	3.4	3.6	-	-	2.9	3.3	2.4	4.5

Soil:	O1	O2	O3	P1	P2	P3	P4	P5	P6	CA1	CA2
N:	10	10	10	-	10	10	10	10	10	10	10
Mean:	15.2	14.6	13.2	-	15.5	18.2	24.8	17.5	17.4	19.5	20.3
Std.Dev.:	3.5	2.5	2.1	-	2.1	2.1	3.6	3.5	2.7	3.5	1.9

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	4751.642	228		
Error:	2284.100	205	11.142	
Treatment:	2467.542	23	107.284	9.63

Significant at $p < 0.0001$

Table B-6. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in Area L2 Soils

Cucumber Plants				Radish Plants			
Soil	Grouping	Critical Range	# of Means	Soil	Grouping	Critical Range	# of Means
N4	a	22.877	26	P4	a	6.480	24
L4	ab	22.751	25	N4	b	6.440	23
P4	abc	22.620	24	CA2	bc	6.399	22
K4	abcd	22.482	23	K4	bc	6.355	21
M4	bcde	22.337	22	CA1	bcd	6.310	20
M6	bcde	22.185	21	M6	bcde	6.261	19
M5	bcdef	22.025	20	M5	bcde	6.209	18
O1	bcdefg	21.856	19	P3	bcde	6.154	17
P5	bcdefg	21.676	18	P5	bcde	6.096	16
P6	bcdefg	21.484	17	P6	bcde	6.033	15
M7	cdefgh	21.279	16	L4	bcde	5.964	14
N3	cdefgh	21.059	15	N6	bcde	5.890	13
CA2	cdefgh	20.821	14	M7	bcde	5.809	12
P2	defghi	20.562	13	M4	bcde	5.720	11
N5	efghi	20.280	12	P2	bcde	5.621	10
CA1	efghi	19.968	11	O1	bcde	5.509	9
O2	fghi	19.621	10	N3	cde	5.381	8
O3	ghi	19.231	9	O2	cde	5.232	7
P3	ghi	18.784	8	K5	cde	5.055	6
K5	hi	18.266	7	N5	de	4.836	5
L6	i	17.646	6	L6	de	4.551	4
N6	j	16.882	5	O3	e	4.148	3
L5	jk	15.888	4	L5	f	3.464	2
L3	jk	14.482	3	N1	f		
N2	k	12.094	2	K1			
P1	k			K2			
K1				K3			
K2				L1			
K3				L2			
L1				L3			
L2				M1			
M1				M2			
M2				M3			
M3				N2			
N1				P1			

Table B-7. ANOVA of Plant Heights of Cucumbers Grown in Group 1 Soils

Soil:	A2	A2'	A3	A4	A5	A6	B4	B5	C1	C2	D1	D2
N:	-	8	10	10	10	10	10	10	10	10	3	10
Mean:	-	12.5	61.7	60.5	117.0	93.6	70.3	96.2	19.8	103.3	14.0	66.5
Std.Dev.:	-	2.9	6.0	5.6	14.2	11.3	11.1	10.6	2.2	12.5	6.1	8.0

Soil:	D3	E1	E2	E3	E4	E5	F1	F3	F4	G1	G2	H1
N:	10	-	10	10	10	10	10	10	10	1	2	10
Mean:	117.6	-	19.9	85.0	69.2	75.2	77.6	69.9	104.8	12.0	7.0	114.1
Std.Dev.:	7.4	-	2.3	11.9	7.8	7.5	6.4	7.2	31.2	-	2.8	12.9

Soil:	H2	H3	H4	I1	I2	I3	J1	CB1	CB2
N:	10	10	10	1	-	10	10	10	10
Mean:	67.6	82.1	73.4	5.0	-	71.8	89.9	73.5	86.1
Std.Dev.:	7.4	8.8	5.7	-	-	11.6	12.7	9.2	10.6

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	236167.109	264		
Error:	27758.800	235	118.123	
Treatment:	208408.309	29	7186.493	60.84

Significant at $p < 0.0001$

Table B-8. ANOVA of Plant Heights of Radishes Grown in Group 1 Soils

Soil:	A2	A2'	A3	A4	A5	A6	B4	B5	C1	C2	D1	D2
N:	3	10	10	10	10	10	10	10	10	10	9	10
Mean:	7.3	6.3	22.4	18.7	26.9	33.5	23.2	26.4	10.0	30.8	6.6	22.3
Std.Dev.:	3.2	2.9	4.8	3.6	4.8	5.0	3.1	5.3	3.9	5.9	2.7	3.2

Soil:	D3	E1	E2	E3	E4	E5	F1	F3	F4	G1	G2	H1
N:	10	5	7	10	10	10	10	10	10	5	7	10
Mean:	32.1	5.0	13.6	22.2	18.4	23.3	26.8	26.9	24.0	5.6	4.7	33.8
Std.Dev.:	9.2	0.7	4.0	4.6	3.0	4.3	5.8	3.8	3.6	2.1	1.5	7.4

Soil:	H2	H3	H4	I1	I2	I3	J1	CB1	CB2
N:	10	10	10	-	-	10	10	10	10
Mean:	25.1	22.1	25.3	-	-	21.9	33.2	24.8	21.3
Std.Dev.:	5.1	4.3	4.3	-	-	3.5	6.4	2.9	3.1

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	24718.409	285		
Error:	5374.132	255	21.075	
Treatment:	19344.277	30	644.809	30.60

Significant at $p < 0.0001$

Table B-9. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in Group 1 Soils

Cucumber Plants

Soil	Grouping	Critical Range	# of Means
D3	a	24.892	30
A5	a	24.779	29
H1	a	24.661	28
F4	ab	24.538	27
C2	abc	24.410	26
B5	bcd	24.276	25
A6	bcde	24.136	24
J1	bcdef	23.990	23
CB2	bcdefg	23.836	22
E3	cdefg	23.674	21
H3	defgh	23.503	20
F1	defgh	23.323	19
E5	efgh	23.131	18
CB1	efgh	22.927	17
H4	efgh	22.709	16
I3	fgh	22.475	15
B4	fgh	22.221	14
F3	fgh	21.946	13
E4	fgh	21.644	12
H2	gh	21.313	11
D2	gh	20.943	10
A3	h	20.527	9
A4	h	20.051	8
E2	i	19.499	7
C1	i	18.838	6
D1	i	18.024	5
A2'	i	16.964	4
G1	i	15.464	3
G2	i	12.916	2
I1	i		
A2			
E1			
I2			

Radish Plants

Soil	Grouping	Critical Range	# of Means
H1	a	8.464	31
A6	a	8.427	30
J1	a	8.388	29
D3	ab	8.349	28
C2	abc	8.307	27
F3	bcd	8.264	26
A5	bcd	8.219	25
F1	bcd	8.171	24
B5	bcd	8.122	23
H4	cde	8.070	22
H2	cde	8.015	21
CB1	cde	7.957	20
F4	cde	7.896	19
E5	de	7.832	18
B4	de	7.763	17
A3	de	7.689	16
D2	de	7.610	15
E3	de	7.524	14
H3	de	7.431	13
I3	de	7.329	12
CB2	de	7.217	11
A4	ef	7.092	10
E4	ef	6.951	9
E2	fg	6.790	8
C1	gh	6.603	7
A2	h	6.380	6
D1	h	6.104	5
A2'	h	5.745	4
G1	h	5.238	3
E1	h	4.375	2
G2	h		
I1			
I2			

Table B-10. ANOVA of Plant Heights of Cucumbers Grown in TNT Ditch Soils

Soil:	AA1	AA2	AA3	AA4	AA5	AA6	BB1	BB2	BB3	BB4	BB5	CC1
N:	10	10	10	10	10	10	10	10	10	10	10	-
Mean:	114.1	79.2	101.0	99.3	97.3	105.2	99.5	111.2	92.0	82.4	105.7	-
Std.Dev.:	9.2	13.8	9.7	9.1	14.1	10.7	16.4	13.7	10.0	9.5	11.1	-

Soil:	CC2	CC3	CC4	CC5	CC6	DD1	DD2	DD3	DD4	DD5	EE1	EE2
N:	10	10	10	10	10	10	10	10	10	10	10	10
Mean:	68.1	81.4	105.9	96.9	90.9	106.3	131.0	85.3	107.0	99.7	121.5	89.8
Std.Dev.:	16.0	9.5	13.1	12.1	8.9	9.4	11.6	11.3	20.1	12.0	11.0	8.6

Soil:	EE3	EE4	EE5	EE6	FF1	FF2	FF3	FF4	CA	CB
N:	10	10	10	10	10	10	-	10	10	10
Mean:	66.8	94.5	94.1	99.5	125.2	69.7	-	122.3	85.2	76.0
Std.Dev.:	16.1	13.9	24.4	11.6	19.8	18.1	-	12.8	9.1	14.4

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	133972.000	319		
Error:	51500.200	288	178.820	
Treatment:	82471.800	31	2660.381	14.88

Significant at $p < 0.0001$

Table B-11. ANOVA of Plant Heights of Radishes Grown in TNT Ditch Soils

Soil:	AA1	AA2	AA3	AA4	AA5	AA6	BB1	BB2	BB3	BB4	BB5	CC1
N:	10	10	10	10	10	10	10	10	10	10	10	6
Mean:	20.0	23.4	19.5	30.3	28.1	26.0	23.0	24.8	20.7	16.0	23.2	9.3
Std.Dev.:	4.0	7.8	3.6	7.5	4.6	4.4	5.1	7.4	3.2	1.2	6.5	3.4

Soil:	CC2	CC3	CC4	CC5	CC6	DD1	DD2	DD3	DD4	DD5	EE1	EE2
N:	10	10	10	10	10	10	10	10	10	10	10	10
Mean:	25.5	27.5	24.0	30.3	18.4	23.2	20.0	17.0	21.5	30.7	28.6	22.9
Std.Dev.:	5.7	6.7	6.2	6.9	4.3	4.2	5.4	4.4	7.2	8.2	3.5	5.7

Soil:	EE3	EE4	EE5	EE6	FF1	FF2	FF3	FF4	CA	CB
N:	10	10	10	10	10	10	3	10	10	10
Mean:	21.2	21.3	19.2	20.3	31.9	23.0	10.0	29.1	20.3	23.9
Std.Dev.:	7.7	5.2	3.6	5.5	6.3	8.4	0	6.4	3.7	6.6

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	16968.979	328		
Error:	9693.733	295	32.860	
Treatment:	7275.245	33	220.462	6.71

Significant at $p < 0.0001$

Table B-12. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in TNT Ditch Soils.

Cucumber Plants				Radish Plants			
Soil	Grouping	Critical Range	# of Means	Soil	Grouping	Critical Range	# of Means
DD2	a	22.847	32	FF1	a	10.295	34
FF1	ab	22.752	31	DD5	ab	10.255	33
FF4	abc	22.653	30	AA4	abc	10.214	32
EE1	abc	22.550	29	CC5	abc	10.171	31
AA1	bcd	22.443	28	FF4	abcd	10.128	30
BB2	bcde	22.332	27	EE1	abcde	10.081	29
DD4	cdef	22.216	26	AA5	abcdef	10.034	28
DD1	cdef	22.094	25	CC3	abcdef	9.984	27
CC4	cdefg	21.968	24	AA6	abcdef	9.932	26
BB5	cdefg	21.835	23	CC2	abcdefg	9.878	25
AA6	cdefg	21.695	22	BB2	abcdefg	9.821	24
AA3	defgh	21.548	21	CC4	abcdefg	9.762	23
DD5	defghi	21.394	20	CB	abcdefg	9.700	22
BB1	defghi	21.230	19	AA2	abcdefg	9.634	21
EE6	defghi	21.056	18	BB5	abcdefg	9.565	20
AA4	defghi	20.871	17	DD1	abcdefg	9.492	19
AA5	defghi	20.673	16	BB1	abcdefg	9.414	18
CC5	defghi	20.460	15	FF2	abcdefg	9.331	17
EE4	defghij	20.230	14	EE2	abcdefg	9.243	16
EE5	defghij	19.980	13	DD4	bcdefg	9.147	15
BB3	efghij	19.706	12	EE4	bcdefg	9.045	14
CC6	efghij	19.405	11	EE3	bcdefg	8.933	13
EE2	fghij	19.069	10	BB3	cdefg	8.811	12
DD3	ghijk	18.692	9	CA	defg	8.676	11
CA	ghijk	18.259	8	EE6	defg	8.526	10
BB4	hijk	17.757	7	DD2	defg	8.357	9
CC3	hijk	17.158	6	AA1	defg	8.164	8
AA2	ijk	16.417	5	AA3	defg	7.940	7
CB	jk	15.454	4	EE5	efg	7.671	6
FF2	k	14.089	3	CC6	fg	7.340	5
CC2	k	11.771	2	DD3	g	6.910	4
EE3	k			BB4	g	6.300	3
CC1				FF3	h	5.263	2
FF3				CC1	h		

Table B-13. ANOVA of Plant Heights of Cucumbers Grown in Lead Azide Soils

Soil:	GG1	GG2	GG3	GG4	GG5	HH1	HH2	HH3	HH4	II1	II2	II4
N:	10	10	10	10	10	10	10	10	10	10	10	10
Mean:	125.0	108.0	122.2	120.9	111.6	111.8	120.2	118.3	117.7	130.2	123.6	115.5
Std.Dev.:	13.8	16.2	9.6	18.2	12.1	8.5	9.8	7.7	14.4	11.3	11.5	12.8

Soil:	II5
N:	10
Mean:	130.8
Std.Dev.:	15.2

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	24724.431	129		
Error:	18992.400	117	162.328	
Treatment:	5732.031	12	477.669	2.94

Significant at $p < 0.01$

Table B-14. ANOVA of Plant Heights of Radishes Grown in Lead Azide Soils

Soil:	GG1	GG2	GG3	GG4	GG5	HH1	HH2	HH3	HH4	II1	II2	II4
N:	10	10	10	10	10	10	10	10	10	10	10	10
Mean:	22.9	27.8	26.0	25.0	26.4	24.5	23.9	30.3	24.7	25.8	24.3	24.9
Std.Dev.:	3.4	6.5	7.3	8.6	4.3	4.5	2.9	7.3	5.7	6.3	3.5	2.7

Soil:	II5
N:	10
Mean:	26.6
Std.Dev.:	4.6

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	3998.531	129		
Error:	3563.500	117	30.457	
Treatment:	435.031	12	36.253	1.19

Not Significant at $p > 0.05$

Table B-15. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in Lead Azide Soils

Cucumber Plants

Soil	Grouping	Critical Range	# of Means
II5	a	19.273	13
II1	ab	19.004	12
GG1	abc	18.709	11
II2	abc	18.379	10
GG3	abc	18.009	9
GG4	abc	17.587	8
HH2	abc	17.095	7
HH3	abc	16.509	6
HH4	abc	15.788	5
II4	abc	14.851	4
H[illegible]	bc	13.526	3
[illegible]	[illegible]	11.284	2
[illegible]	[illegible]		

Radish Plants

Soil	Grouping	Critical Range	# of Means
HH3	a	8.348	13
GG2	a	8.232	12
II5	a	8.104	11
GG5	a	7.961	10
GG3	a	7.801	9
II1	a	7.618	8
GG4	a	7.405	7
II4	a	7.151	6
HH4	a	6.839	5
HH1	a	6.433	4
II2	a	5.859	3
HH2	a	4.888	2
GG1	a		

Table B-16. ANOVA of Plant Heights of Cucumbers Grown in Group 61 Soils

Soil:	JJ1	JJ2	JJ3	JJ4	JJ5	JJ6	JJ7
N:	10	10	10	10	10	10	10
Mean:	122.9	118.9	116.2	107.1	145.4	113.7	82.5
Std.Dev.:	7.6	7.9	11.0	13.3	11.3	9.2	10.1

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	27830.871	69		
Error:	6599.300	63	104.751	
Treatment:	21231.571	6	3538.595	33.78

Significant at $p < 0.0001$

Table B-17. ANOVA of Plant Heights of Radishes Grown in Group 61 Soils

Soil:	JJ1	JJ2	JJ3	JJ4	JJ5	JJ6	JJ7
N:	10	10	10	10	10	10	10
Mean:	27.9	30.1	30.5	26.4	27.9	27.3	25.3
Std.Dev.:	4.1	7.4	6.2	2.6	7.8	5.0	7.0

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Value
Total:	2467.486	69		
Error:	2257.800	63	35.838	
Treatment:	209.686	6	34.948	0.98

Not Significant at $p > 0.05$

Table B-18. Newman-Keuls Analysis of All Treatments, Pairwise, and Ranked From High to Low: Cucumber and Radish Plant Heights (mm), Grown in Group 61 Soils

Cucumber Plants				Radish Plants			
Soil	Grouping	Critical Range	# of Means	Soil	Grouping	Critical Range	# of Means
JJ5	a	13.940	7	JJ3	a	8.154	7
JJ1	b	13.453	6	JJ2	a	7.869	6
JJ2	bc	12.854	5	JJ1	a	7.519	5
JJ3	bc	12.079	4	JJ5	a	7.065	4
JJ6	bc	10.987	3	JJ6	a	6.426	3
JJ4	c	9.147	2	JJ4	a	5.350	2
JJ7	d			JJ7	a		

Blank

APPENDIX C

Seed Emergence Rates of Cucumber and Radish Plants Grown in JAAP Soils

Emergence Rates (%) of Cucumbers and Radishes Grown in JAAP Soils.
Number Emerging/20 seeds planted: (cucumber/radish)

Area 2

Soil	%
Q1	90/95
Q2	40/50
Q3	95/100
Q4	40/65
Q5	100/95
R2	95/90
R3	100/100
R4	95/100
R5	90/95
R6	100/95
S2	95/95
S3	100/100
S4	95/95
S5	95/100
S6	100/85
CA	95/95

Area L2

Soil	%
K1	0/0
K2	0/5
K3	0/0
K4	95/95
K5	90/60
L1	0/20
L2	0/10
L3	5/20
L4	95/80
L5	50/40
L6	100/95
M1	0/0
M2	0/0
M3	0/0
M4	100/100
M5	85/100
M6	100/95
M7	75/90
N1	0/5
N2	5/0
N3	75/90
N4	95/100
N5	100/95
N6	90/100
O1	100/95
O2	85/95
O3	85/85
P1	10/0
P2	60/95
P3	100/100
P4	100/95
P5	95/95
P6	95/100
C1	100/95
C2	100/100

Group 1

Soil	%
A2	0/80
A2'	40/75
A3	95/100
A4	100/95
A5	100/100
A6	95/100
B4	100/100
B5	100/100
C1	90/100
C2	95/95
D1	15/90
D2	100/95
D3	100/95
E1	0/50
E2	100/95
E3	100/95
E4	100/95
E5	100/100
F1	100/100
F3	100/100
F4	100/100
G1	5/60
G2	10/70
H1	95/60
H2	100/100
H3	100/90
H4	100/100
I1	5/5
I2	0/10
I3	100/100
J1	95/100
C1	100/95
C2	95/95

TNT Ditch

Soils	%
AA1	85/95
AA2	65/90
AA3	95/95
AA4	100/100
AA5	95/100
AA6	90/60
BB1	95/90
BB2	100/90
BB3	100/95
BB4	95/100
BB5	95/100
CC1	35/20
CC2	100/100
CC3	100/100
CC4	90/100
CC5	95/100
CC6	95/100
DD1	90/100
DD2	100/100
DD3	100/100
DD4	100/100
DD5	95/100
EE1	95/100
EE2	100/100
EE3	100/100
EE4	100/90
EE5	95/100
EE6	95/100
FF1	90/100
FF2	95/95
FF3	90/100
FF4	70/100
CA	100/95
CB	100/100

Lead Azide

Soils	%
GG1	90/85
GG2	75/80
GG3	90/75
GG4	65/85
GG5	75/85
HH1	80/90
HH2	85/95
HH3	85/75
HH4	100/85
II1	100/85
II2	90/75
II4	90/90
II5	85/80

Group 61

Soils	%
JJ1	95/95
JJ2	75/65
JJ3	80/75
JJ4	100/90
JJ5	85/90
JJ6	80/75
JJ7	85/95

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APPENDIX D

Survival Rates of Cucumber and Radish Plants Grown in JAAP Soils

Survival Rates (%) of Cucumbers and Radishes Grown in JAAP Soils.
Number Surviving to Day 14/10 Plants: (cucumber/radish)

Area 2		Area L2		Group 1		TNT Ditch		Lead Azide	
Soil	%	Soil	%	Soil	%	Soils	%	Soils	%
Q1	100/100	K1	0/0	A2	0/30	AA1	85/95	GG1	90/85
Q2	50/80	K2	0/0	A2'	80/100	AA2	65/90	GG2	75/80
Q3	100/100	K3	0/0	A3	100/100	AA3	95/95	GG3	90/75
Q4	60/60	K4	100/100	A4	100/100	AA4	100/100	GG4	65/85
Q5	100/100	K5	100/100	A5	100/100	AA5	95/100	GG5	75/85
				A6	100/100	AA6	90/60		
R2	100/100	L1	0/0					HH1	80/90
R3	100/100	L2	0/0	B4	100/100	BB1	95/90	HH2	85/95
R4	100/100	L3	10/0	B5	100/100	BB2	100/90	HH3	85/75
R5	100/100	L4	100/100			BB3	100/95	HH4	100/85
R6	100/100	L5	100/80	C1	100/100	BB4	95/100		
		L6	100/100	C2	100/100	BB5	95/100	II1	100/85
S2	100/100							II2	90/75
S3	100/100	M1	0/0	D1	30/90	CC1	35/20	II4	90/90
S4	100/100	M2	0/0	D2	100/100	CC2	100/100	II5	85/80
S5	100/100	M3	0/0	D3	100/100	CC3	100/100		
S6	100/100	M4	100/100			CC4	90/100	Group 61	
		M5	100/100	E1	0/50	CC5	95/100	Soils	%
CA	100/100	M6	100/100	E2	100/70	CC6	95/100	JJ1	95/95
		M7	100/100	E3	100/100			JJ2	75/65
				E4	100/100	DD1	90/100	JJ3	80/75
		N1	0/10	E5	100/100	DD2	100/100	JJ4	100/90
		N2	10/0			DD3	100/100	JJ5	85/90
		N3	100/100	F1	100/100	DD4	100/100	JJ6	80/75
		N4	100/100	F3	100/100	DD5	95/100	JJ7	85/95
		N5	100/100	F4	100/100				
		N6	100/100			EE1	95/100		
				G1	10/50	EE2	100/100		
		O1	100/100	G2	20/70	EE3	100/100		
		O2	100/100			EE4	100/90		
		O3	100/100	H1	100/100	EE5	95/100		
				H2	100/100	EE6	95/100		
		P1	20/0	H3	100/100				
		P2	100/100	H4	100/100	FF1	90/100		
		P3	100/100			FF2	95/95		
		P4	100/100	I1	10/0	FF3	90/100		
		P5	100/100	I2	0/0	FF4	70/100		
		P6	100/100	I3	100/100				
						CA	100/95		
		C1	100/100	J1	100/100	CB	100/100		
		C2	100/100						
				CB1	100/100				
				CB2	100/100				

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APPENDIX E

EARTHWORM STATISTICAL DATA
Analysis of Covariance (ANCOVA) of Weight Differences of Earthworms Raised in JAAP Soils

Table E-1. ANCOVA of Weight Differences (g) of Earthworms in Area 2 Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.19207	14	0.01372	6.16	0.0006*

* Significant

Table E-2. ANCOVA of Weight Differences (g) of Earthworms in Area L2 Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.02094	21	0.00100	3.27	0.0035*

* Significant

Table E-3. ANCOVA of Weight Differences (g) of Earthworms in Group 1 Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.15489	24	0.00645	6.31	0.0001*

* Significant

Table E-4. ANCOVA of Weight Differences (g) of Earthworms in TNT Ditch Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.15912	29	0.00549	5.26	0.0001*

* Significant

Table E-5. ANCOVA of Weight Differences (g) of Earthworms in Lead Azide Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.01848	12	0.00154	5.64	0.0027*

* Significant at $p < 0.01$

Table E-6. ANCOVA of Weight Differences (g) of Earthworms in Group 61 Soils

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Soil Site	0.00270	7	0.00039	2.99	0.0857*

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APPENDIX F

SURVIVAL RATE (%) OF EARTHWORMS RAISED IN JAAP SOILS

Area 2	Area L2	Group 1	TNT Ditch	Lead Azide	Group 1
Q1- 100	K1- 0	A2- 10	AA1- 100	GG1- 100	JJ1- 90
Q2- 0	K2- 0	A2'- 0	AA2- 100	GG2- 100	JJ2- 100
Q3- 80	K3- 0	A3- 100	AA3- 100	GG3- 100	JJ3- 100
Q4- 0	K4- 100	A4- 90	AA4- 100	GG4- 100	JJ4- 100
Q5- 90	K5- 100	A5- 10	AA5- 100	GG5- 100	JJ5- 100
		A6- 100	AA6- 100		JJ6- 100
R2- 100	L1- 0			HH1- 100	JJ7- 100
R3- 100	L2- 0	B4- 80	BB1- 100	HH2- 100	
R4- 100	L3- 0	B5- 100	BB2- 100	HH3- 100	
R5- 100	L4- 90		BB3- 100	HH4- 100	
R6- 100	L5- 20	C1- 90	BB4- 100		
	L6- 90	C2- 100	BB5- 100	II1- 100	
S2- 100				II2- 100	
S3- 100	M1- 0	D1- 0	CC1- 0	II4- 90	
S4- 100	M2- 0	D2- 90	CC2- 100	II5- 100	
S5- 100	M3- 0	D3- ?	CC3- 100		
S6- 70	M4- 100		CC4- 100		
	M5- 90	E1- 0	CC5- 100		
C1- 90	M6- 100	E2- 100	CC6- 100		
C2- 93	M7- 100	E3- 100			
		E4- 100	DD1- 100		
	N1- 0	E5 100	DD2- 100		
	N2- 0		DD3- 100		
	N3- 100	F1- 100	DD4- 100		
	N4- 100	F3- 100	DD5- 100		
	N5- 100	F4- 90			
	N6- 100		EE1- 100		
		G1- 0	EE2- 100		
	O1- 60	G2- 0	EE3- 100		
	O2- 100		EE4- 100		
	O3- 100	H1- 100	EE5- 100		
		H2- 100	EE6- 100		
	P1- 0	H3- 100			
	P2- 100	H4- 100	FF1- 100		
	P3- 80		FF2- 100		
	P4- 100	I1- 0	FF3- 0		
	P5- 100	I2- 0	FF4- 100		
	P6- 100	I3- 90			
			CO- 100		
	CO- 100	J1- 100			
		CO- 75			

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APPENDIX G

MICROTOX ASSAY
EC_{50} VALUES AND CONFIDENCE FACTORS

Table G-1. Toxicity of Soil Extracts Using Microtox 15-Min Assay-Area 2 Soils

Sampling Location	EC_{50} (% Extract) and 95% Confidence Factors		EC_{50} > 100%
S5	85.9	(43.18 - 170.9)*	R2
R3	67.5	(36.58 - 124.4)	R4
Q1	29.2	(21.73 - 39.36)	R5
Q2	5.73	(5.262 - 6.242)	R6
Q4	5.77	(3.882 - 8.572)	S2
			S3
			S4
			S5
			S6
			Q3
			Q5
			Control

* 5-min EC_{50}; insufficient 15-min data

Table G-2. Toxicity of Soil Extracts Using Microtox 15-Min Assay-Area L2 Soils

Sampling Location	EC_{50} (% Extract) and 95% Confidence Factors		EC_{50} > 100%
K1	2.44	(0.095 - 61.95)	K4
K2	3.86	(0.0028 - 5289)	K5
K3	2.93	(0.891 - 9.624)	L4
L1	3.45	(1.162 - 10.26)	L6
L2	3.87	(0.711 - 21.12)	M4
L3	9.57	(4.091 - 22.37)*	M5
L5	6.41	(2.350 - 17.49)	M7
M1	4.80	(0.601 - 38.37)	N3
M2	2.28	(0.287 - 18.19)	N4
M3	8.70	(2.048 - 36.97)	O1
M6	57.7	(37.47 - 88.89)	O2
N1	3.43	(0.630 - 18.67)	O3
N2	0.992	(0.525 - 1.876)	P2
N5	8.91	(6.152 - 12.90)	P3
N6	21.7	(7.749 - 60.87)	P4
P1	1.63	(0.002 - 1690)	P5
			P6
			Control

* 5-min EC_{50}; insufficient 15-min data

Table G-3. Toxicity of Soil Extracts Using Microtox 15-Min Assay-Group 1 Soils

Sampling Location	EC_{50} (% Extract) and 95% Confidence Factors		EC_{50} > 100%
A1	4.22	(2.195 - 8.110)	A5
A2'	6.14	(2.190 - 17.20)	A6
A3	52.20	(32.22 - 84.64)	B4
A4	29.90	(21.58 - 41.48)	C2
B5	28.80	(19.53 - 42.45)	D2
C1	8.40	(2.731 - 25.85)	D3
D1	3.17	(1.570 - 6.413)	E3
E1	3.34	(1.030 - 10.83)	E4
G1	4.80	(1.592 - 14.47)	E5
G2	3.94	(1.982 - 7.827)	F1
I1	2.55	(0.401 - 16.18)	F3
I2	4.78	(2.352 - 9.726)	F4
			H1
			H2
			H3
			H4
			I3
			J1
			Control

Table G-4. Toxicity of Soil Extracts Using Microtox 15-Min Assay-TNT Ditch Complex Soils

Sampling Location	EC_{50} (% Extract) and 95% Confidence Factors		EC_{50} > 100%	
BB2	54.10	(13.82 - 212.1)	AA1	DD2
CC1	4.78	(2.240 - 10.22)	AA2	DD3
CC3	51.20	(22.58 - 116.3)	AA3	DD4
FF3	6.14	(4.134 - 9.112)	AA4	DD5
			AA5	EE1
			AA6	EE2
			BB1	EE3
			BB3	EE4
			BB4	EE5
			BB5	EE6
			CC2	FF1
			CC4	FF2
			CC5	FF4
			DD1	Control

Table G-5 Toxicity of Soil Extracts Using Microtox 15-Min Assay-Lead Azide Area Soils

EC_{50} > 100%
GG1
GG2
GG3
GG4
GG5
HH1
HH2
HH3
HH4
II1
II2
II4
II5
Control

Table G-6 Toxicity of Soil Extracts Using Microtox 15-Min Assay-Group 61 Soils

EC_{50} > 100%
JJ1
JJ2
JJ3
JJ4
JJ5
JJ6
JJ7
Control